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Research and Development Service
Washington, D.C. 20591

Analysis of Helicopter Accident Risk Exposure Near Heliports, Airports, and Unimproved Sites

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Final Report

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U.S. Department of Transportation

Federal Aviation Administration

NOTICE

U.S. Department
of Transportation

**Federal Aviation
Administration**

800 Independence Ave., S.W
Washington, D.C. 20591

FEB 28 1992

Dear Colleague:

Enclosed is **FAA/RD-90/9, Analysis of Helicopter Accident Risk Exposure Near Heliports, Airports, and Unimproved Sites.** This effort was initiated to provide the community with an authoritative review of helicopter landing site accidents and to provide guidance on ways to reduce such accidents.

When a heliport is proposed, community objections often focus on the issue of safety and the concern that there is a risk associated with having a heliport as a neighbor. Analysis of accident data shows that heliports are safe neighbors. While people often voice concerns about the possibility of a helicopter accident causing them personal injury or property damage, this document shows that such an event is extremely rare. Heliport proponents may find this document useful as an authoritative reference in responding to such community concerns.

At the same time, however, this analysis shows that during the 1977 - 1986 time period 34-39 percent of all helicopter accidents occurred at or within one mile of landing sites. Of the total number of helicopter accidents, the approximate percentages that occurred at different types of landing sites are as follows: 13-18 percent at or near airports, 3-5 percent at or near heliports, and 9-18 percent at or near unimproved landing sites. With approximately 3-8 percent of all helicopter accidents, National Transportation Safety Board records do not specify the nature of the landing site.

Clearly, if the rotorcraft community is to continue to reduce its accident rates, reductions must be achieved in the number of accidents taking place at or near landing sites. Such reductions can be achieved through a combination of actions including training, design, operational procedures, etc. This report fccuses heavily on what should be done via changes in landing site design standards and guidelines.

This document also continues the development of the topic of rotorcraft "target level of safety" first discussed in FAA/DS-88/12, Minimum Required Heliport Airspace Under Visual Flight Rules. In choosing a target level of safety, the FAA and industry have an objective method for decision making on issues such as the minimum VFR heliport airspace required for

curved approaches and departures. This report recommends several target levels of safety on issues of heliport design. These levels are based on historical accident trends.

The FAA is sensitive to the issue of cost. We do not wish to propose million dollar "solutions" to thousand dollar problems. Increasingly, we are using accident analysis to identify the most significant problems. Once identified, we want to work with industry in developing and publicizing cost effective solutions to these problems. We welcome any suggestions that you may wish to make in this regard. We also welcome your recommendations on other rotorcraft research and development needs. Please send your suggestions and recommendations to:

Vertical Flight Program Office, ARD-30
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Enclosure

Technical Report Documentation Page

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16. Abstract

This report discusses the development of relevant safety indicators to be used in the assessment of risk exposure due to heliport design and operational standards. Since helicopter accidents have been relatively rare events, historical data at heliports are somewhat limited. Therefore, the approach described herein is to develop the total helicopter risk exposure due to all causes and then estimate what proportion of that risk should be allocated to various circumstances associated with specific heliport design and helicopter operational characteristics.

This approach introduces the need for analysis and quantification of risk using a parameter or parameters that both industry and government agree are within a logical framework. Data on the number of helicopter accidents per year, accidents per 100,000 hours of flight time, accidents per 100,000 mission segments, accident rates for selected mission types, occupant risk of serious injury, and neighborhood risk are presented. Finally, civil helicopter accidents are categorized by the facilities near which they occur (heliport, airport, etc.) and by the operating facility design parameters that impact operational risk.

This report is one of a series of three dealing with helicopter accidents near heliports, airports, and unimproved landing areas. The other reports are:

"Analysis of Helicopter Mishaps at Heliports, Airports, and Unimproved Sites" DOT/FAA/RD-90/8,
"Composite Profiles of Helicopter Mishaps at Heliports and Airports," DOT/FAA/RD-91/1

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DEDICATION

This document is dedicated to the Helicopter Safety Advisory Council (HSAC) in recognition of their success in reducing accident rates in offshore helicopter operations. The rotorcraft community would do well to consider how the organizational structure and methods of the HSAC could be adapted to help continue the reduction of accident rates in other segments of the vertical flight industry.

PREFACE

The research effort reported herein was managed by the Federal Aviation Administration, Vertical Flight Program Office (ARD-30), under contract to Systems Control Technology, Inc. (SCT). The study methodology and the initial research efforts were performed by Richard J. Adams of Advanced Aviation Concepts (AAC). The detailed analysis of accident data, provided by the National Transportation Safety Board (NTSB), and helicopter operations data, provided by the Federal Aviation Administration (FAA), was performed by Edwin D. McConkey, and Len D. Dzamba of SCT. Project direction and the conceptual construction of a target level of safety were contributed by Robert D. Smith of the FAA Vertical Flight Program Office. The report is a joint effort of the above-mentioned analysts.

The authors would like to thank employees of the NTSB for their support in providing accident data for this research project. In particular, the authors want to thank NTSB personnel in the statistical data office who were of immeasurable help in providing much of the summary accident data and in interpreting the accident statistics.

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1.0 INTRODUCTION

Many approaches can be used to determine the relative risk associated with heliport design and operation. The primary objective of this analysis is to assess the risk associated with helicopter operations on an annual basis and to develop a meaningful and reasonable apportionment of that risk to movements on or within 1 mile of a landing site. A secondary objective is to further analyze the available accident data by type of operation such as air taxi, executive transport, instruction, personal, etc, for purposes of determining whether the risk is uniform or whether it may vary by mission type. The overall project is a complex task requiring certain ground rules and assumptions. Wherever assumptions are made, the historical precedent or the basis for them is referenced.

In this analysis, "risk" is used to refer to the likelihood of a helicopter accident which results in significant aircraft damage and/or injury to the pilot (or aircrew), passengers, and/or third parties such as linemen, mechanics or any individual in the immediate vicinity (within 1 mile) of a designated landing site. For the purposes of this analysis, a designated landing site is a landing area at an airport, a heliport, a private helipad, a grass landing strip, a parking lot, or any other improved or unimproved landing site where helicopters operate more than just once or twice per year. Although there have been a few accidents resulting from objects falling from aircraft, these are extremely rare and are not considered in this analysis.

1.1 RISK EXPOSURE ANALYSIS

In determining risk exposure, a widely accepted approach relies on historical accident statistics and accident rates. These rates represent average risk exposure levels made up of many components. There are numerous ways of organizing these component accident statistics, each of which can prove useful and instructional in identifying significant areas of risk exposure. The initial effort described herein investigates overall helicopter accident rates as a basis for a more detailed analysis in subsequent efforts, also reported in this document. These detailed analyses include assessments of risk exposure in the following contexts:

- risk exposure at takeoff/landing sites (including airports, heliports, and unimproved landing sites);

- risk exposure to the occupants of a helicopter (pilot, crew, and passengers);

- risk exposure to the neighborhood (people and property) in the vicinity of a heliport;

- risk exposure associated with heliport/landing site design;

- risk exposure by type of mission (including personal, business, instructional, corporate/executive, aerial applications, aerial observations, other work, other, air taxi, and scheduled commuter);

- comparison of the risk exposure rates of helicopters with those of general aviation, air carrier, and scheduled commuter fixed-wing aircraft; and

- projected risk exposure of helicopter operations through the remainder of the decade and the establishment of target levels of safety for heliport design.

Safety is affected by four basic risk factors, as discussed in "Aeronautical Decisionmaking for Helicopter Pilots" (reference 1). Pilot or human error accounts for 60 percent, and by some accounts as much as 90 percent, of all helicopter accidents, regardless of location, phase of flight, or type of operation. Most of the remainder are generally attributable to mechanical failure (powerplant, fuel system, airframe/rotor system, etc.). In addition, the environment (wind, cloud ceiling, visibility, precipitation and/or temperature) and the type of operation or mission (offshore, aerial applications, instruction, etc.) can affect the risk. These cause factors can change over time due to the quality and quantity of training, changes in aircrew experience levels, technological improvements, type of mission, and the degree of safety control imposed (monitoring, inspection, and enforcement). Therefore, selection of a time period for the study and the helicopter environment are each significant to the outcome of this effort. The analysis presented herein includes a comprehensive look at 26 years of historical data (1964 through 1989) for developing the overall operational risk picture. The analysis is then "fine-tuned" to address the problems observed within 1 mile of heliports, airports, and other landing sites in the 1977 through 1986 time frame.

1.2 REPORT ORGANIZATION

Section 2.0 provides the foundation for this analysis by first determining the overall risk of helicopter operations on an annual basis. Risk exposure comparisons are made between helicopter and fixed-wing general aviation, air carrier, and scheduled commuter operations. Although helicopter operations are normally included in these categories, they have been separated for purposes of this study. Section 3.0 provides an analysis of the apportionment of this risk to the six flight phases associated with operations in and around heliports. Different analytical approaches and databases are used in an attempt to converge on an order of magnitude estimate suitable for characterizing heliport risk exposure. Section 4.0 illustrates a method of further refining this risk exposure by type of operation. Section 5.0 analyzes the risk to residents, buildings, and transient occupants in the vicinity of takeoff/landing sites. Finally, section 6.0 looks at predicted risk exposure through the year 2000. Section 6.0 also addresses target levels of safety and establishes helicopter accident rate goals related to design issues for the year 2000.

1.3 REPORT LIMITATIONS

This report treats all helicopters as a generic fleet and does not attempt to identify differences among helicopters types (single-engine piston, single-engine turbine, twin-engine turbine, home built, military surplus, and helicopters that are significantly modified by other than the manufacturer). These aircraft types differ significantly in terms of characteristics and missions. The intent of this report is to provide only a basic understanding of the safety history of helicopters in general. No attempt was made in this

study to evaluate or compare the risk exposure of the various types of helicopters or specific makes/models of helicopters.

Many of the analyses described in this report used helicopter accident data provided by the National Transportation Safety Board (NTSB). These data are collected and archived by the NTSB for accident investigation purposes. In this report, some of this data is combined with data from other sources (e.g., FAA surveys) to evaluate helicopter accident rates in various operational situations, a purpose that differs somewhat from the original intent of the data. The authors believe the results presented herein are a fair representation of helicopter accident rates, but they also recognize limitations inherent in using data collected for other purposes (e.g., NTSB accident investigation data) or through survey methods (e.g., FAA helicopter operational data).

2.0 RISK EXPOSURE ASSESSMENT METHODS

Many forms of measurement can be used in assessing the overall risk of helicopter operations at and around heliports and airports. Historically, the measures selected have been directly related to the specific goal of the analysis. Table 1 illustrates a variety of parameters used by various segments of the helicopter industry and the aviation community to compare risk exposure.

TABLE 1 VARIATIONS IN RISK MEASUREMENT

	DESCRIPTION	USER(s)	UNITS
1.	Accident Rates over a Unit of Time	NTSB/FAA	Accidents/100,000 Hours
2.	Probability of Mission Completion	Operators	Accidents/100,000 Missions
3.	Patient Transportation	Air Ambulance	Accidents/100,000 Patients Transported
4.	Transportation Risk	Air Carriers	Accidents/100,000 Passenger Miles
5.	Risk of Serious Injury	Aircraft Occupants	Serious Injuries/100,000 Occupant Hours
6.	Neighborhood Risk	Planning Boards	Average Years Between Accidents

Despite agreement that helicopter safety has steadily improved over the years, a variety of opinions exist within the aviation industry as to the appropriate indicators/measurements of those improvements. The following quotation, taken from correspondence with Mr. Roy Fox (reference 2), illustrates this point:

> "Annual accident counts, accidents per fleet size ratios, and fatal accident rate per flight hour should not be used as the only measures of risk exposure. The safety measurement method to be used is strictly determined by the subject of primary concern. The denominator of the frequency rate will include this primary concern. If aircraft damage frequency is of primary concern, then an accident per aircraft flight hour method is appropriate. If the mission is the primary concern, then accidents per mission (e.g., launch, departure, takeoff, flight, trip, passenger mile or patient transport) is appropriate. If the primary concern is the risk of an accident in a neighborhood without regard to the aircraft occupants, then the years between accidents measured for that specific neighborhood is appropriate. With the safety of the aircraft occupant as the primary concern, the relative risk of serious injury per occupant flight hour is the best method."

The following sections present data from all of these perspectives in an attempt to provide a comprehensive examination of helicopter accident risk exposure.

The objectives of this analysis are to:

- analyze various data normalization procedures,
- quantify the risk associated with heliport design and operation,
- compare helicopter risk with the risk associated with both air carrier and general aviation aircraft operations, and
- determine several measures of risk exposure within 1 mile of a heliport (risk to the aircraft, the mission, the occupants of the helicopter, and the neighborhood).

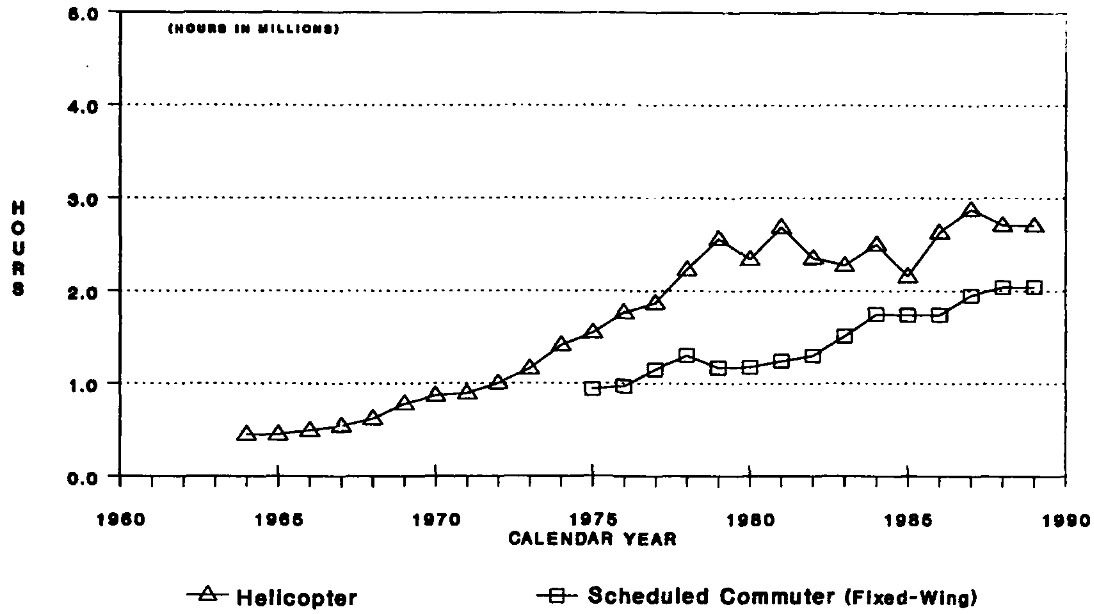
2.1 ANNUAL HOURS FLOWN/NUMBER OF ACCIDENTS

To provide the proper perspective for any of the various parameters, it is necessary to analyze the risk exposure of helicopter flight compared to some common denominator. Typically, the number of annual hours flown is used for this purpose. As stated in the introduction, this analysis begins with a review of 26 years worth of annual operating statistics and accident data. Figures 1 and 2 show the annual hours flown by helicopters and fixed-wing general aviation, air carrier, and scheduled commuters for this 26 year period.* (Note the difference in scales for the helicopter and scheduled commuter operations versus the general aviation and air carrier operations.)

As shown, annual helicopter utilization increased by more than a factor of six between 1964 (447,000 hours flown) and 1990 (2,800,000 hours flown). The bulk of the increase in annual hours flown by helicopters has been in the air taxi, aerial observation, and executive transport mission categories.

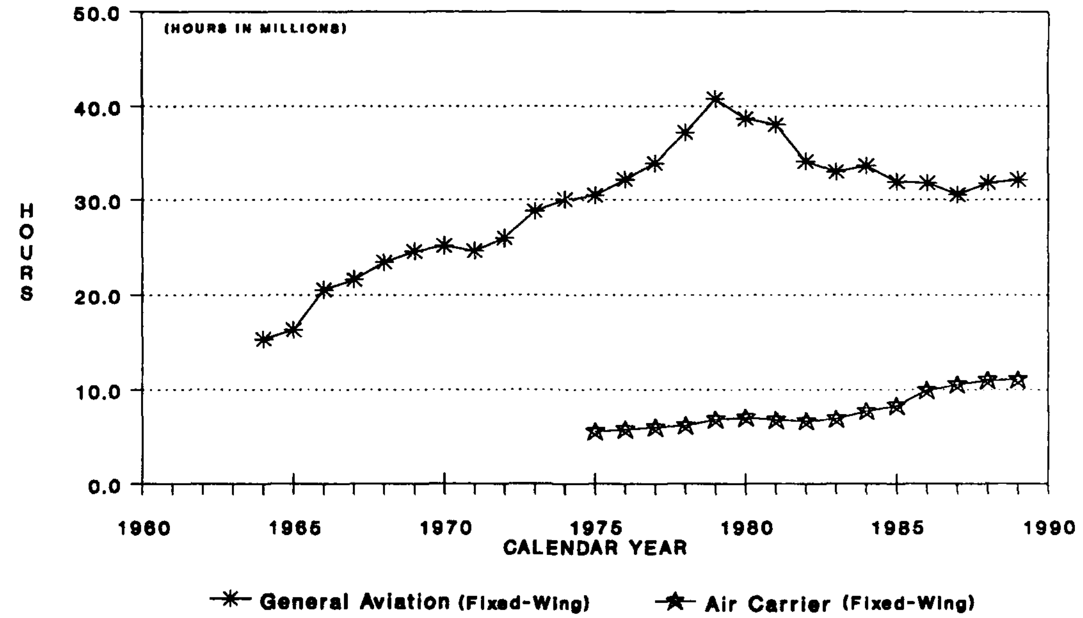
In contrast, hours flown annually by general aviation as a whole increased significantly over the first part of this same time period, peaked in 1979 at 43 million hours, and has remained relatively flat at about 32 million hours per year since about 1982. For general aviation, the 1989 annual hours flown are about double the annual hours flown in 1964. Figure 1 also shows that since 1975 the number of scheduled commuter and air carrier annual hours flown have doubled.

*NOTE: The types of operations defined as scheduled commuter and air carrier have changed during the period of the study. However, they have remained consistent since 1975. Therefore, all scheduled commuter and air carrier data presented in the study will be from 1975 to the present. The types of operations defined for helicopters and general aviation have remained consistent since 1964; therefore, these data are presented from 1964 to the present.



SOURCE: A) General Aviation Activity and Avionics Survey (Reference 19)
B) Annual Review of Aircraft Accident Data (Reference 21)

FIGURE 1 TOTAL ANNUAL HOURS FLOWN (HELICOPTER, SCHEDULED COMMUTER)



SOURCE: A) General Aviation Activity and Avionics Survey (Reference 19)
B) Annual Review of Aircraft Accident Data (Reference 21)

FIGURE 2 TOTAL ANNUAL HOURS FLOWN (AIR CARRIER, GENERAL AVIATION)

Table 2 shows the percentage breakdown for United States registered helicopters by engine type, including single-engine piston, single-engine turbine, and twin-engine turbine. The table also shows the corresponding percent of flight hours flown for each category from 1984 through 1988. It is interesting to note that the single-engine piston category has the largest percentage of registered aircraft; however, the single-engine turbine category represents the highest utilization category, with more than 60 percent of the total number of flight hours flown.

TABLE 2 U.S. REGISTERED HELICOPTERS AND UTILIZATION BY ENGINE TYPE

Engine Type	Percentage of Helicopters Registered (1)	Percentage of Helicopter Flight Hours (2)
Single-Engine Piston	53%	25.9%
Single-Engine Turbine	36%	61.5%
Twin-Engine Turbine	11%	12.6%

(1) U.S. Registered Helicopters, November 30, 1990
(2) Total U.S. Helicopter Flight Hours, 1984 through 1988

2.1.1 Total Annual Helicopter Accidents, 1964 Through 1989

The number of accidents involving helicopters varied from year to year during the 26 year period investigated with an overall downward trend, despite a significant increase in annual flight hours over the same time period. As illustrated in figure 3, for the most part, the annual number of helicopter accidents hovered between 220 to 260 with an average of 249 accidents for the 10 year period from 1964 to 1974. It then increased slightly to a range of 270 to 300 annual accidents with an average of 283 from 1975 to 1983. However, since 1983 the number of annual helicopter accidents has been steadily decreasing to less than 200 accidents per year for the years 1987 through 1989. In fact, the decline in helicopter accidents since 1982 has been dramatic with approximately 100 fewer accidents per year today!

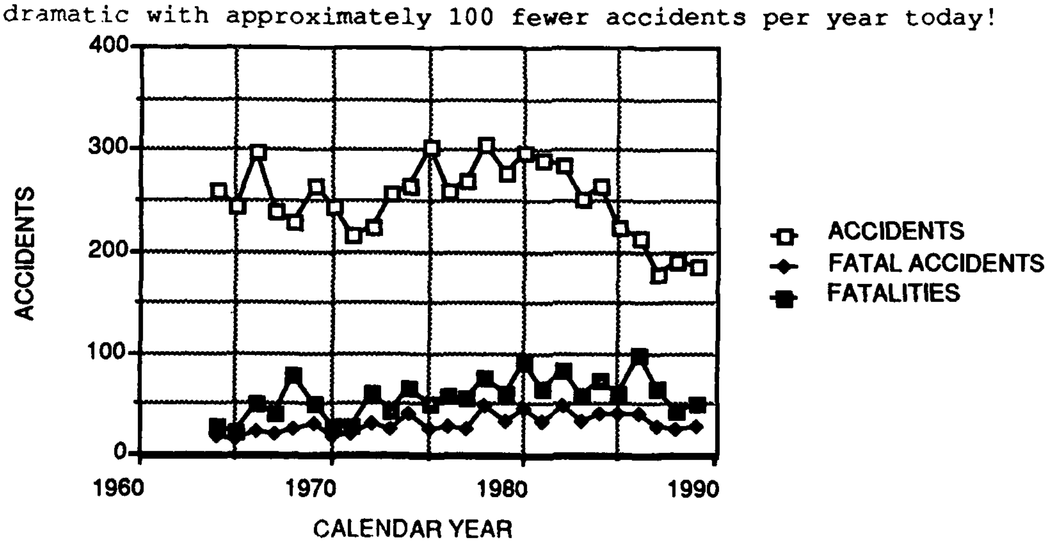


FIGURE 3 CIVIL ROTORCRAFT ACCIDENT HISTORY, 1964 TO 1989

It is interesting to note that while the annual hours flown (see figure 1) have been increasing gradually since 1979 (averaging about 2.5 million hours), the annual number of accidents has steadily decreased. It was during this time that the manufacturers, NASA, and the FAA began investigating human error accidents and developing a variety of human factors programs aimed at reducing those accidents.

2.1.2 Fatalities as an Accident Risk Measurement

During the 26 year period, 1964 to 1989, the number of fatal accidents increased about 30 percent. There were 20 to 25 fatal accidents on the average from 1964 to 1974. This increased slightly to the 35 to 40 range during the 1975 to 1983 time period. Since 1984, the number of fatal accidents has stabilized at about 35 accidents per year (average 1984 through 1988), with the most recent data, 1987 through 1989, showing an average of only 28 fatal accidents. It must be emphasized that exposure (total annual operating hours) has increased sixfold during this same period.

Table 3 shows the number of accidents, fatal accidents, number of fatalities, operating hours and associated accident rates for the 26 year period analyzed.

In the 1964 to 1974 time period, only 8 to 10 percent of the total helicopter accidents were fatal. This percentage increased during the 1975 to 1983 time frame to the 12 to 14 percent level. During the most recent period from 1984 to 1987, the fatal to total accident ratio has averaged almost 17 percent. A linear-curve-fit was performed for the 26 year period investigated, resulting in a positive slope to the straight line approximating the data. This data and the linear-curve-fit are shown in figure 4.

As shown in figure 4, the percentage of fatal accidents increased steadily during the 26 year period investigated. This occurred over a period when the number of flight hours increased sixfold, the size of the typical helicopter increased from the Bell 47 (2 passengers) to the Bell 206/Hughes 500 (5-7 passengers), and the accident rate due to mechanical failure decreased. The percentage of fatal accidents is expected to continue to increase as the average helicopter occupancy increases with larger aircraft.

This trend appears to point to a higher number of helicopter occupants and to limited progress in the area of helicopter crashworthiness. Discussions with representatives of the helicopter manufacturing industry provided their perspective on this issue. More people are flying larger helicopters, and when a crash occurs, there are more likely to be fatalities due to the lack of improvements in crashworthiness. Manufacturers know how to build crashworthy helicopters. The problem, however, is twofold. First, certification requirements formerly did not mandate shoulder harnesses for all occupants. In addition, FAA does not require the installation of energy attenuating seating, crash resistant fuel systems, etc., even though these technologies are available and widely used by the military and in some civil helicopters. Secondly, operators seldom voluntarily request these options due to cost and weight considerations.

TABLE 3 HELICOPTER ACCIDENT DATA ANALYSIS, 1964 THROUGH 1989 (1)

YEAR	TOTAL ACCIDENTS	FATAL ACCI-DENTS	FATAL-ITIES	ANNUAL HOURS	ACCIDENTS/ 100,000 HOURS	PERCENT FATAL ACCIDENTS	FATAL ACCIDENT RATE (3)
1964	259	19	29	447,000	57.94	7.34	4.25
1965	244	16	24	450,000	54.22	6.56	3.56
1966	298	24	50	492,000	60.57	8.05	4.88
1967	239	21	42	538,000	44.42	8.79	3.90
1968	230	26	80	617,000	37.28	11.30	4.21
1969	265	31	51	778,000	34.06	11.70	3.98
1970	244	19	29	867,000	28.14	7.79	2.19
1971	217	21	29	890,000	24.38	9.68	2.36
1972	224	31	61	1,000,000	22.40	13.84	3.10
1973	258	25	44	1,158,000	22.28	9.69	2.16
1974	265	40	65	1,414,000	18.74	15.09	2.83
1975	302	25	50	1,547,000	19.52	8.28	1.62
1976	261	28	58	1,762,000	14.81	10.73	1.59
1977	270	26	57	1,868,000	14.45	9.63	1.39
1978	308	48	76	2,228,000	13.82	15.58	2.15
1979	280	34	60	2,555,000	10.96	12.14	1.33
1980	302	46	92	2,338,000	12.92	15.23	1.97
1981	291	33	66	2,685,000	10.84	11.34	1.23
1982	289	49	83	2,350,000	12.30	16.96	2.08
1983	253	33	58	2,271,000	11.14	13.04	1.45
1984	265	39	74	2,495,000	10.62	14.72	1.56
1985	224	37	61	2,155,000	10.39	16.59	1.72
1986	213	42	99	2,625,000	8.11	19.72	1.60
1987	179	29	66	2,283,000	7.84	16.20	1.27
1988	190	26	43	2,707,000	7.02	13.68	0.96
1989	185	28	51	2,800,000	6.61	15.14	1.00
TOT	6,555	796	1,498	43,320,000			
AVG	252	31	58	1,666,154	15.13 (2)	12.14 (2)	1.84 (2)

(1) Includes all helicopter operations.
(2) Weighted average based on 26 year total values.
(3) Fatal accidents per 100,000 flight hours.

Source: A) General Aviation Activity and Avionics Survey (FAA).
B) Annual Review of Aircraft Accident Data (NTSB).

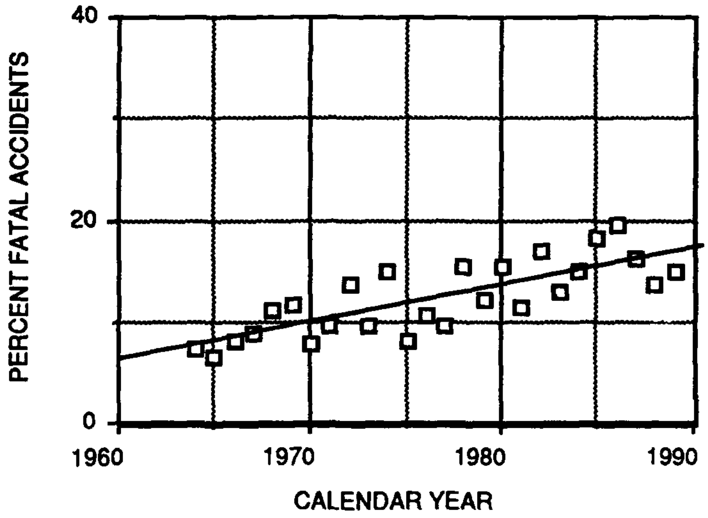


FIGURE 4 PERCENT FATAL CIVIL ROTORCRAFT ACCIDENTS, 1964 TO 1989

The crashworthiness problem has been recognized by the FAA, and as a result, Federal Aviation Regulations (FAR) are being amended to require future helicopters applying for type certification to have energy attenuating seats and shoulder harnesses for all occupants (Amendments 27-25 and 29-29). Dynamic seat tests will be required of all new helicopter designs to prove that they will function as desired.

FAA published Notice of Proposed Rulemaking (NPRM) 89-32 in the Federal Register (54FR50688) on December 8, 1989. This proposed change was approved August 16, 1991. The regulation requires shoulder harnesses for newly manufactured helicopters at all seat locations on helicopters manufactured after September 16, 1992. The FAA is also considering changes with regard to crash resistant fuel systems (CFRS), as described in NPRM 90-24 published in the Federal Register (55FR41000) on October 5, 1990.

2.2 ANNUAL ACCIDENT RATE DATA

In contrast to the percentage of fatal accidents, the rate of occurrence of all helicopter accidents per 100,000 hours flown shows a significant decrease since 1964. As shown in figure 5, the downward trend in the annual accident rate has been consistent for this 26 year time period.

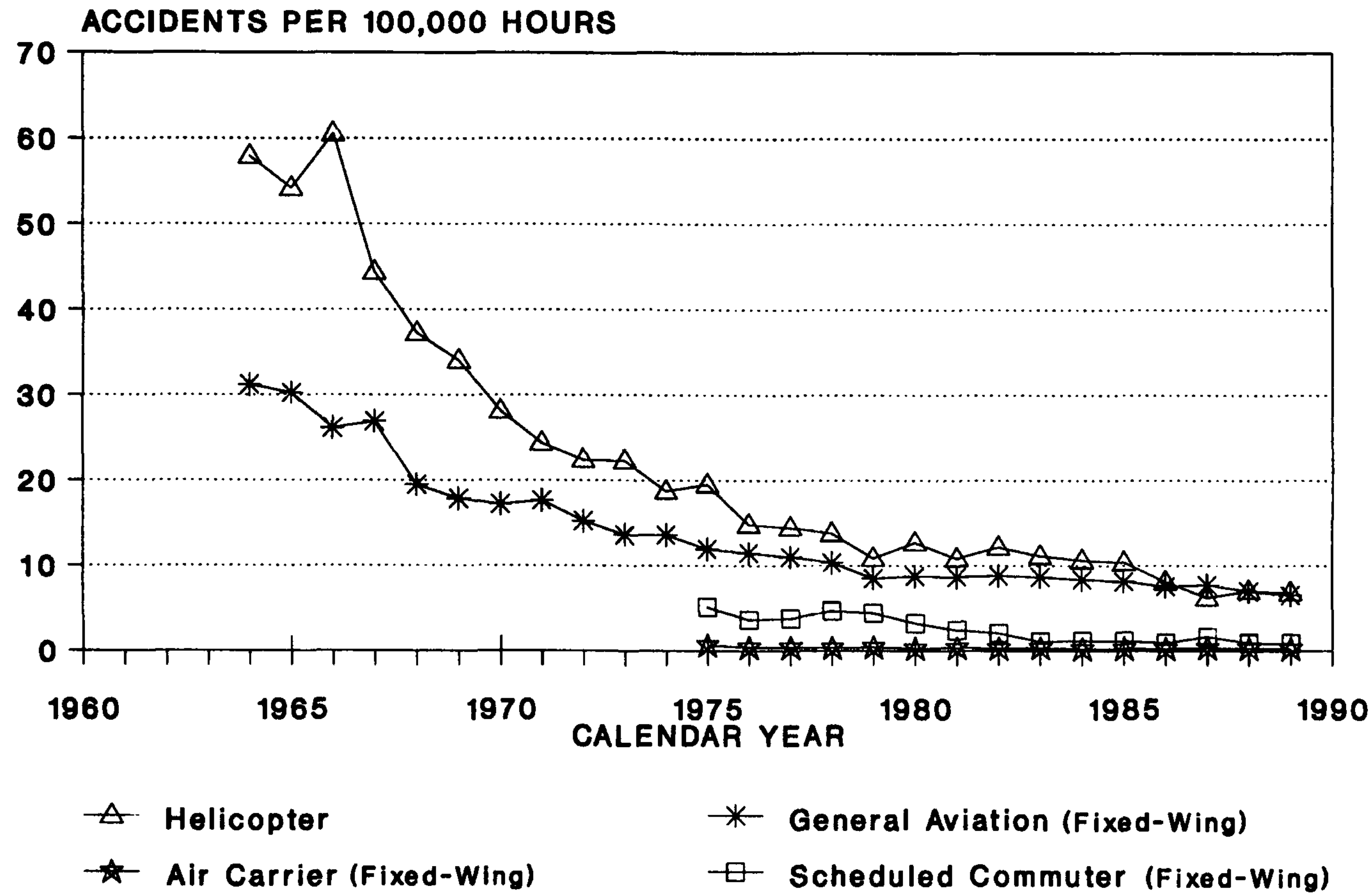


FIGURE 5 ANNUAL ACCIDENT RATE

This figure shows that the accident rate has decreased by nearly a factor of 10 (60.0 to 6.2 per 100,000 flight hours) in the 26 years analyzed. General aviation accident rates, as a whole, have also declined over this 26 year period. However, as can be seen in figure 5, helicopter accident rates have shown a greater improvement over this time period relative to the general aviation rates. In fact, over the last 4 years, helicopter accident rates have been about equal to general aviation accident rates (reference 5).

Other analysts have evaluated helicopter accident rates from a slightly different perspective. For example, table 7 from reference 34 (table included as figure 6) presents a matrix of accident rates for different helicopter configurations by the accident cause factors for 1984 through 1988. In this analysis, the combined helicopter fleet accident rate for all causes was 8.54 accidents per 100,000 flight hours. This rate is consistent with the helicopter accident rates presented in table 3 and figure 5.

Table 7. USA-registered helicopter accident rates (Source: NTSB/FAA for 1984 through 1988) (Accidents per 100,000 flight hours)

Type of Aircraft	Engine Only Airworthiness	Non-engine Airworthiness	All Airworthiness	All Causes
All Helicopters	1.22	1.08	2.30	8.54
Single Piston	1.99	2.09	4.09	17.83
Twin Turbine	0.35	1.25	1.59	4.37
Single Turbine (all)	1.08	0.61	1.69	5.49
Bell 206 Single Turbine	0.88	0.17	1.05	4.28

FIGURE 6 TABLE 7 FROM REFERENCE 34

It is significant to note that the helicopter accident rate has not only steadily decreased while annual flight hours have increased, but that the operating environment, mission, and performance demands have consistently risen for helicopters as compared to the typical fixed-wing aircraft. Although it is difficult to develop a direct correlation between the decrease in accident rates and industry evolution, the following events undoubtedly have had a significant impact on the resultant improvements.

First, 1965 saw the introduction of the turbine-powered helicopter into commercial operations. This technology was less complex than piston operated helicopters, was easier to maintain, offered greater reliability, and reduced pilot workload. The turbine powered civil fleet grew continuously from its introduction and in 1980 reached the point of comprising half of the civil helicopters in operational use.

Second, beginning in the early 1970's, there was a huge influx of highly-trained, post-Vietnam military pilots into civil operations. While these pilots brought with them a mixture of both good and bad flying habits relative to civilian requirements, the effects of this have not been statistically analyzed.

In the 1980's it was widely recognized that, for the most part, accidents due to mechanical failure had been minimized. The corollary to this was that the primary cause of accidents was recognized overwhelmingly to be human error. Consequently, programs were initiated to reduce human error through awareness programs, cockpit resource management, and decisionmaking training. Although there appears to be a leveling off of the accident rate from 1987 through 1989, safety, risk assessment, decisionmaking, and the human element remain the focus of accident prevention.

During this same 26 year period, the fatal accidents per 100,000 flight hours also steadily decreased. As shown in figure 7, the downward trend was from a high of 4.88 in 1966 to a low that averaged 1.00 for 1987 through 1989. The trend for both general aviation and helicopter fatal accident rates has been downward over these 26 years. Since 1970, the average rates for general aviation and helicopters have been approximately equal. However, over the last 3 years, helicopter fatal accident rates have averaged 32 percent less than general aviation rates.

Table 4 presents this same data showing the steady decrease in terms of 5 year averages. Looking at the data in the table clearly shows a threefold reduction in the fatal accident rate for this period.

It is noted here that there are some significant limitations in using fatal accident rate data. This is due to the fact that the average number of helicopter occupants is increasing and to the fact that the number of occupants varies significantly from one helicopter mission to another.

TABLE 4 AVERAGE FATAL ACCIDENT RATES, 1964 TO 1988

TIME PERIOD	AVERAGE ANNUAL FATAL ACCIDENTS/100,000 HRS.
1964 TO 1968	4.2
1969 TO 1973	2.8
1974 TO 1978	1.9
1979 TO 1983	1.6
1984 TO 1988	1.4

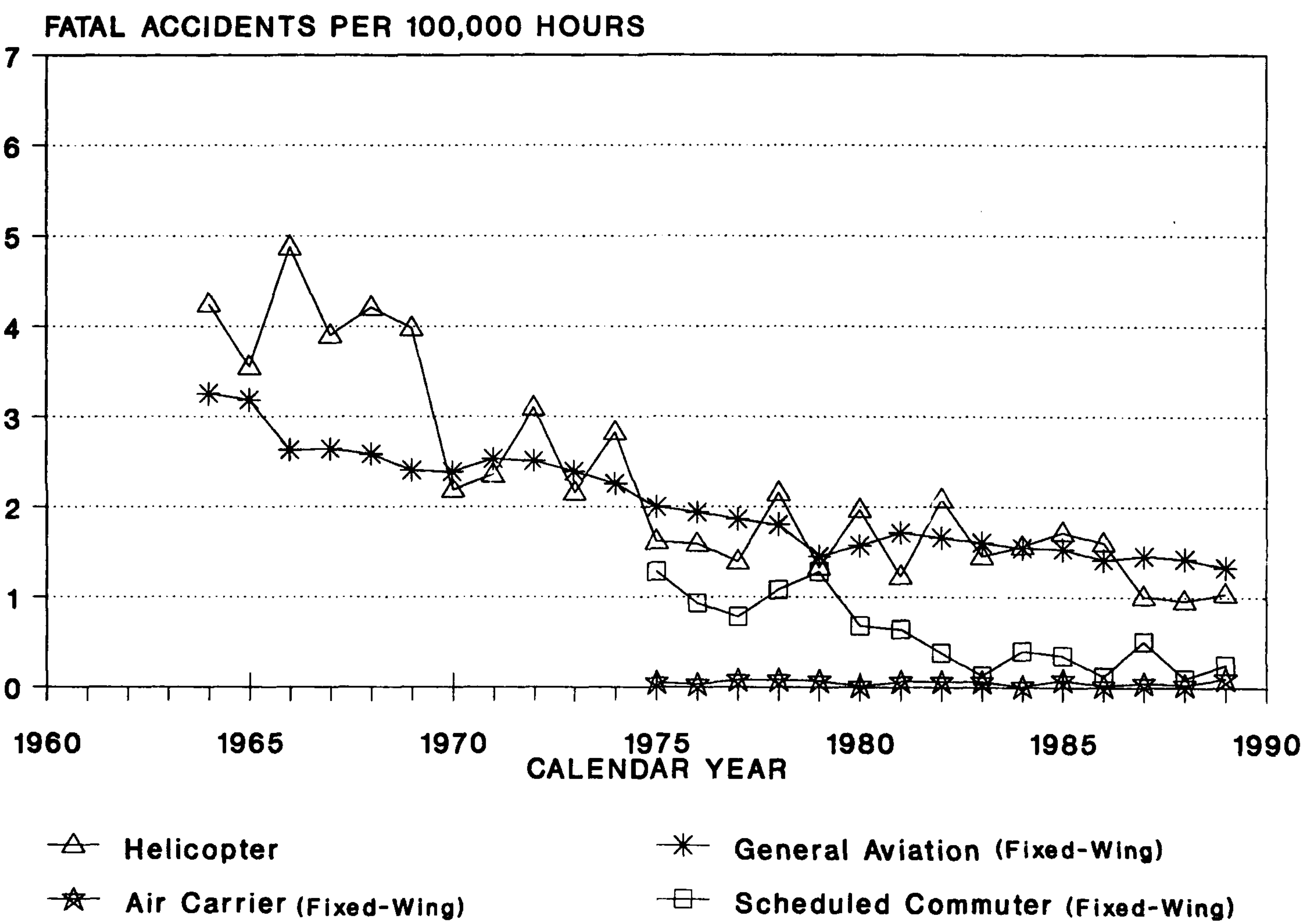


FIGURE 7 ANNUAL FATAL ACCIDENT RATE

3.0 RELATIVE RISK OF HELICOPTER OPERATIONS NEAR LANDING SITES

The previous section provided the reader with an overall understanding of the safety history of the helicopter fleet and a comparison with fixed-wing segments of aviation. This section provides an analysis of the relative risk of a helicopter accident occurring on or within 1 mile of a heliport, airport, or other landing site. These other locations include undesignated, unimproved, and remote heliports. The analyses use civil helicopter data only and are applications of two distinctly different methodologies. Both methodologies used the NTSB's computerized case file data base. The analysis methods were:

1. using the initial phase of flight assigned to the accident by the investigator, count those accidents that occurred in phases of flight that typically happen near or at the landing site, and

2. combine information on the location of the accident relative to the landing site, and the narrative description of the accident to determine accidents that occurred within 1 mile of the landing site.

These two different analytical approaches were used in an attempt to converge on an order of magnitude estimate suitable for characterizing relative risk of helicopter accidents on or within 1 mile of a landing site.

3.1 ESTIMATES BASED ON NTSB ANNUAL REPORTS

The first analytical technique used to obtain a risk estimate was based on data obtained from the NTSB computerized case file data base for calendar years 1977 to 1986. In order to approximate the number of accidents that occurred within 1 mile of a landing site (NTSB accident reports do not always specify distance), the accident data was categorized by phase of flight. This was the first technique used and required some basic assumptions.

Table 5 specifies the phases of flight used by the NTSB to characterize accidents. Those listed under the column entitled "landing site accidents" were the categories selected for this analysis.

TABLE 5 CIVIL HELICOPTER ACCIDENT CATEGORIES BY PHASE OF FLIGHT

LANDING SITE ACCIDENTS	ACCIDENTS NOT CONSIDERED
Standing	Climb to cruise
pre-flight; engines operating;	Cruise
idling rotors	Cruise-normal
Taxi	
to takeoff; from landing; aerial	Descending
Takeoff	Holding
ground run; initial climb	Maneuvering
Approach	Aerial Application
VFR pattern final approach;	Turn to Reverse Direction
FAF/outer marker to threshold (IFR)	Missed Approach
Landing	Other
flare/touchdown; roll-out	Unknown
Hover	

As shown in table 5, six flight phases defined by the NTSB were selected to define helicopter accidents at landing sites. These phases were: standing, taxi, takeoff, approach, landing, and hover. The specific phases and the sub-categories listed were used in combination with the referenced NTSB data files to obtain the summary data listed in table 6.

TABLE 6 ACCIDENTS NEAR LANDING SITES BASED ON PHASE OF FLIGHT (1)

YEAR	STATIC/TAXI HOVER	TAKEOFF	LANDING	TOTAL LANDING SITE ACCIDENTS (2)	TOTAL HELICOPTER ACCIDENTS
1977	34	48	50	132	270
1978	41	51	52	144	308
1979	31	51	47	129	280
1980	36	47	60	143	302
1981	34	48	75	157	291
1982	37	44	54	135	289
1983	35	53	39	127	253
1984	42	40	43	125	265
1985	44	29	30	103	224
1986	39	36	17	92	213
TOTAL	373	447	467	1,287	2,695
PERCENT LANDING SITE ACCIDENTS	29.0%	34.7%	36.3%	100.0%	
PERCENT TOTAL HELICOPTER ACCIDENTS				48.0%	100.0%

(1) Includes all helicopter missions (general aviation, air taxi, and air carrier).
(2) Based on selected study phases-of-flight.

Source: NTSB Computerized Aviation Accident Data Files (Factual, Cause Factor, and Narrative Files), Calendar Years 1977 through 1986.

As shown in table 6, the total number of accidents near landing sites based upon the NTSB computerized data is 1,287 for the 10 year period analyzed. Based on this analysis, the number of accidents within 1 mile of a landing site is 48 percent of the 2,695 (from table 3) helicopter accidents occurring during the same time frame.

There is a recognized shortcoming in this flight phase analysis approach. Some of the flight phase categories could arguably apply to accidents that occurred beyond the distance limit of 1 mile from the landing site.

Specifically, the subcategories labeled VFR pattern final approach, FAF/route marker to threshold (IFR), and hover may contain accidents that occur beyond the 1 mile distance limit of the study. Similarly, the subcategory labeled missed approach may contain accidents that should be included within the distance limit. Overall it is believed that this method likely overestimates the number of accidents occurring within a mile of the landing site.

3.2 ESTIMATES BASED ON A REVIEW OF NTSB CASE FILES

The second analytical technique used to count the number of helicopter accidents on or near landing sites made use of the accident location data contained in the NTSB factual data base. On the surface, it appears that this analysis technique should yield more reliable data than did the flight phase technique. However, there is a complicating factor. Over the 10 year period of interest, the NTSB used three different formats in their data bases. Also, the data elements, although similar, are not identical, and the accident location does not have the same resolution. For example, the data prior to 1982 has a quarter-mile resolution near the landing site. The data after 1982 has a 1 mile resolution, and the 1982 data has only a 5 mile resolution. In addition, only the data prior to 1982 contains a specific heliport category for the accident location. The 1982 and the post-1982 accident files contain only airport and airstrip categories for accident location. In these cases the type of landing facility was obtained from the narrative description of the accident.

Counts of accidents occurring within 1 mile of the landing facilities were made using the NTSB's pre-1982 and post-1982 computerized data files. The results are presented in table 7. The data for pre-1982 was obtained primarily from the factual data file using the accident location categories. Data for post-1982 was obtained using a combination of the accident location category, distance from the airport category, and the accident narrative description. Analysis of the 1982 data base revealed that, due to the 5 mile resolution of the location data, it was not possible to pinpoint the location of many accidents within the desired 1 mile distance from the landing area. Therefore, this data is omitted from table 7.

Table 7 presents the count of helicopter accidents within 1 mile of a landing site using the accident location method. Excluding 1982 data, table 7 shows that 880 (37 percent) of the 2,406 (from table 3) helicopter accidents occurring over this 9 year period met the 1 mile or less criteria of the study. This is about 11 percent less than the percentage obtained using the flight phase method. Annually, over the 9-year period, 34 to 39 percent of helicopter accidents occurred within 1 mile of a landing site (95 percent confidence interval). Of the two methods, the accident location method, which uses the NTSB factual data, is believed to provide the greater accuracy. However, the flight phases method does provide valuable insight regarding the relative number of accidents occurring during each phase of flight.

A more detailed breakdown of accidents near specific types of landing sites was also performed. Counts of accidents near airports, heliports, and unimproved sites are also presented in table 7. For the airport and heliport facilities, 9 years of data (1977 through 1986, excluding 1982) were used.

There were 374 accidents identified as being within 1 mile of an airport. This is 16 percent of the 2,406 helicopter accidents in this period. Annually, over the 9-year period, 13 to 18 percent of helicopter accidents occurred within 1 mile of an airport (95 percent confidence interval). There were 106 accidents identified as being within 1 mile of a heliport. This represents 4 percent of the total number of accidents. Annually, over the 9-year period, 3 to 5 percent of helicopter accidents occurred within 1 mile of a heliport (95 percent confidence interval). Data were obtained for accidents within 1 mile of an unimproved site for the period from 1983 through 1986. Over this 4 year period there were 146 accidents that were identified as occurring within 1 mile of an unimproved landing site. This represents 15 percent of the 955 helicopter accidents (from table 3) in these 4 years. Annually, over the 4-year period, 9 to 18 percent of helicopter accidents occurred within 1 mile of an unimproved site (95 percent confidence interval). Also, during this period, it was not possible to identify a specific type of facility for 57 accidents. Thus, 6 percent of the accidents occurred at a site that was not specified in the accident report. Annually, over the 4-year period, 3 to 8 percent of the helicopter accidents occurred at sites that could not be determined from the NTSB data file (95 percent confidence interval).

TABLE 7 ACCIDENTS NEAR LANDING SITE BASED ON LOCATION DATA

YEAR	AIRPORT	HELIPORT	UNIMPROVED	UNKNOWN	TOTAL LANDING SITE ACCIDENTS	TOTAL HELICOPTER ACCIDENTS
1977	53	6	*	30	89	270
1978	35	18	*	56	109	308
1979	43	12	*	36	91	280
1980	39	14	*	45	98	302
1981	56	9	*	39	104	291
Subtotal 77-81	226	59	*	206	491	1,451
1982	**	**	**	**	**	289
1983	43	9	54	8	114	253
1984	36	9	31	24	100	265
1985	42	14	33	11	100	224
1986	27	15	28	14	84	213
Subtotal 83-86	148	47	146	57	398	955
Total***	374	106	-	263	889	2,406

* Unimproved was not included as a separate category prior to 1982.

** The 1982 NTSB database does not contain enough information to support an analysis of accidents within 1 mile of a landing site.

*** Excluding 1982.

Figure 8 illustrates the relative order of magnitude of helicopter accidents at landing sites using the two different analytical techniques, and an estimate of the number of accidents occurring at heliports. As shown in the figure, the two techniques (the NTSB data using the flight phase method (—•—) and the detailed accident location method (+)) show similar trends and indicate a definite decline since 1981. The two methods appear to be converging for the post-1982 data sets.

Table 8 summarizes the estimates of total civil helicopter accidents at landing sites using the two estimation techniques.

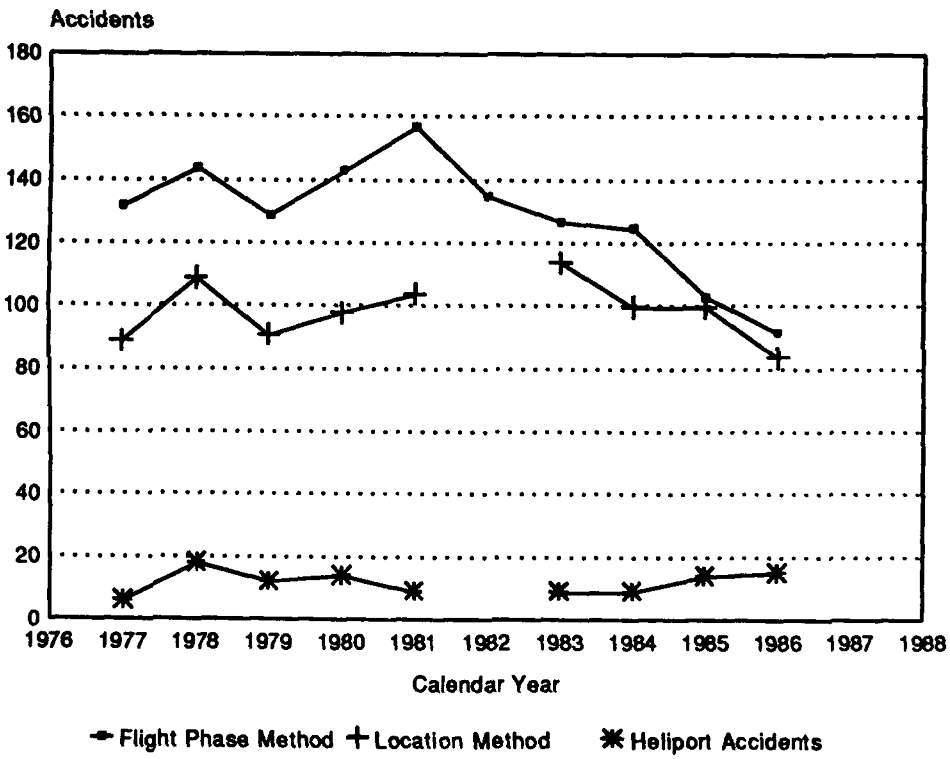


FIGURE 8 HELICOPTER ACCIDENTS NEAR LANDING SITES

TABLE 8 CIVIL ACCIDENTS OCCURRING WITHIN 1 MILE OF A LANDING SITE
(1977 Through 1986)

	NUMBER	SAMPLE SIZE	PERCENT
Helicopter Accidents Occurring Within 1 Mile of a Landing Site (Flight Phase Method, 1977-1986)	1,287	2,695	48
Helicopter Accidents Occurring Within 1 Mile of a Landing Site (Accident Location Method, 1977-1981, 1983-1986)	889	2,406	37
Helicopter Accidents Occurring Within 1 Mile of an Airport (1977-1981, 1983-1986)	374	2,406	16
Helicopter Accidents Occurring Within 1 Mile of a Heliport	106	2,406	4
Helicopter Accidents Occurring Within 1 Mile of an Unimproved Site (1983-1986)	146	955	15
Helicopter Accidents Occurring at Unspecified Locations (1983-1986)	57	955	6

4.0 RISK EXPOSURE BY TYPE OF OPERATION

The previous sections analyzed helicopter accident risk from an overall historical perspective in section 2.0, and from the perspective of accident risk at or near landing sites in section 3.0. The following discussion analyzes helicopter risk from yet another perspective - that is, the risk associated with a particular type of operation or mission. Risk exposure by type of operation was examined from two perspectives: accidents per 100,000 hours and accidents per 100,000 mission segments. In this analysis all helicopter accidents were considered, those within 1 mile of a landing site and those greater than 1 mile from landing sites.

The approach that was used in the accidents per 100,000 hours analysis was to collect helicopter accident data from NTSB case files and categorize these accidents by the "kinds of flying" category. Annual accident rates were computed by dividing the number of accidents per year for each mission type by the corresponding number of annual hours flown for each mission type. The hours flown data were taken from the annual reports of the FAA General Aviation Activity and Avionics Survey for the calendar years of interest. The years covered in this analysis were 1983 through 1986. This time period was chosen because FAA and NTSB have used the same categories for mission types (referred to as "kind of flying" by both FAA and NTSB) since 1983. The analysis was truncated after 1986 because the available NTSB computerized case files were incomplete for the years 1987 and later. The category definitions for the various mission types are shown in appendix A.

The approach used to calculate accidents per 100,000 mission segments was somewhat more difficult. The FAA, in their annual General Aviation Activity and Avionics Survey report, presents data on the number of landings for various aircraft types including piston engine and turbine engine helicopters. These data, when coupled with the annual hours flown data, yield an average mission duration statistic that applies to all helicopter operations. A second source of helicopter operations data can be found in a 1987 survey of all helicopter owners which was reported in reference 7. Although the hours flown and fleet size data resulting from this survey for the various missions are different from the FAA's data, which is the principal subject of reference 7, the survey does contain valuable information on annual operations per helicopter that is not available elsewhere. Section 4.3 compares the number of missions per hour calculated from the two different data sets and shows they are in quite good agreement, 2.01 versus 1.92. The 1987 survey data were used to estimate average mission durations and mission segments per hour. These statistics then were used with the data on accidents per 100,000 hours to compute accidents per 100,000 mission segments.

Fatal accident data by mission type were obtained from the NTSB case files for the years 1983 through 1986. These data were used to compute fatal accidents per 100,000 hours and per 100,000 mission segments for each mission type.

Due to the relatively small number of accidents in each mission category and the difficulty in quantifying hours flown in the vicinity of a landing site, no attempt was made to isolate by mission category those accidents that occurred within the vicinity of heliports and airports. Therefore, the

following analysis includes all helicopter accidents over the 4-year time period from 1983 through 1986.

4.1 ACCIDENT RATES BY HOURS FLOWN

NTSB helicopter accident case files for the years 1983 through 1986 were reviewed and sorted by mission type. The results of this review are shown in table 9. These accident statistics were used with the operations data obtained from the FAA General Aviation Activity and Avionics Survey for the corresponding years, shown in table 10, to compute accident rates by mission type. The results of this analysis are shown in figure 9. It should be noted that the operations data, shown in table 10, was obtained by sampling and statistical methods. As a result, operations, particularly in some of the smaller categories (such as the "scheduled commuter" and "other work" categories) are subject to significant errors, as indicated by the corresponding percent standard error values in table 10. These errors also affect the corresponding accident rate figures. In order to account for these errors, average accident rates were calculated from the accumulated accidents and operations data for the 4 year period. The high, low, and average rates for each mission type are shown in figure 9.

The accident rates for the "personal" category are significantly higher than any other category, by an order of magnitude in many cases. The accident rate for the "business" category is somewhat greater than the average of all rotorcraft. On the other hand, the accident rates for "corporate/executive," "aerial observation," and "air taxi" are all significantly less than the average for all rotorcraft.

The NTSB performed a special study of rotorcraft accidents for the years 1977 through 1979 (reference 17). In this study they performed a similar analysis of accident rates by mission type. Figure 10 shows a comparison of the 1977 through 1979 accident rate data from the NTSB study with the 1983 through 1986 accident rate data from the present study. Some mission categories from the current study have been combined to form categories that are consistent with the earlier study. Average rates over the time periods of interest are presented in both cases.

Figure 10 shows that the accident rates for the "personal/business" and "other" categories are higher in the current study. The higher rate shown for the "personal/business" category in the later study is significantly influenced by the high accident rate for "personal" rotorcraft shown in figure 9. All other categories show improvement in accident rates in the latter period.

The "personal" category includes amateur-built helicopters. These are classified as experimental helicopters and are usually built from kits. With amateur-built aircraft, both helicopters and fixed-wing, it is not unusual for such aircraft to crash in the initial flight tests. In effect, the pilot functions as manufacturer, test pilot, instructor, and student in what may be a type and size of aircraft in which the pilot has never before flown. Under these circumstances, it's not surprising that the accident rate is high. In

TABLE 9 HELICOPTER ACCIDENTS BY MISSION TYPE (1983-1986)

MISSION TYPE	1983	1984	1985	1986
Personal	45	50	37	47
Business	31	33	27	16
Instruction	29	23	27	24
Corporate/Executive	3	5	7	5
Aerial Applications	38	42	34	36
Aerial Observation	10	7	7	12
Other Work	27	15	17	16
Other*	41	42	38	27
Scheduled Commuter	3	1	1	0
Air Taxi	26	47	30	29
Total	253	265	225	212

* Includes rental category

Source: NTSB Case Files

TABLE 10 ROTORCRAFT+ HOURS FLOWN BY MISSION TYPE (1983-1986)
(Thousands of Hours)

MISSION TYPE	1983		1984		1985		1986	
Personal	24	(33)*	41	(21)	54	(22)	38	(19)
Business	60	(34)	76	(20)	190	(35)	99	(30)
Instruction	163	(30)	178	(19)	114	(26)	140	(25)
Corporate/Executive	766	(19)	344	(19)	306	(20)	356	(20)
Aerial Applications	204	(15)	167	(24)	203	(19)	247	(23)
Aerial Observation	181	(24)	340	(19)	490	(21)	450	(19)
Other Work	207	(34)	46	(35)	111	(29)	64	(37)
Other**	120	(35)***	408	(20)***	235	(37)***	296	(22)
Scheduled Commuter	10	(41)	8	(150)	11	(107)	133	(61)
Air Taxi	552	(21)	887	(16)	437	(23)	803	(16)
Total	2,271	(7)	2,495	(6)	2,155	(8)	2,625	(7)

\+ The FAA's data includes hours flown for all rotorcraft. The number of hours flown for non-helicopter rotorcraft (e.g., gyrocopters) was considered small enough to be of little significance in the analysis. Assuming helicopter hours flown equaled rotorcraft hours flown was considered to be within the error bounds of the data.

* Numbers in parentheses represent percent standard error. The high numbers for individual mission types indicate that the data is limited in accuracy. Note that the percent standard error numbers are considerably lower for the total fleet, indicating that these data are reliable.

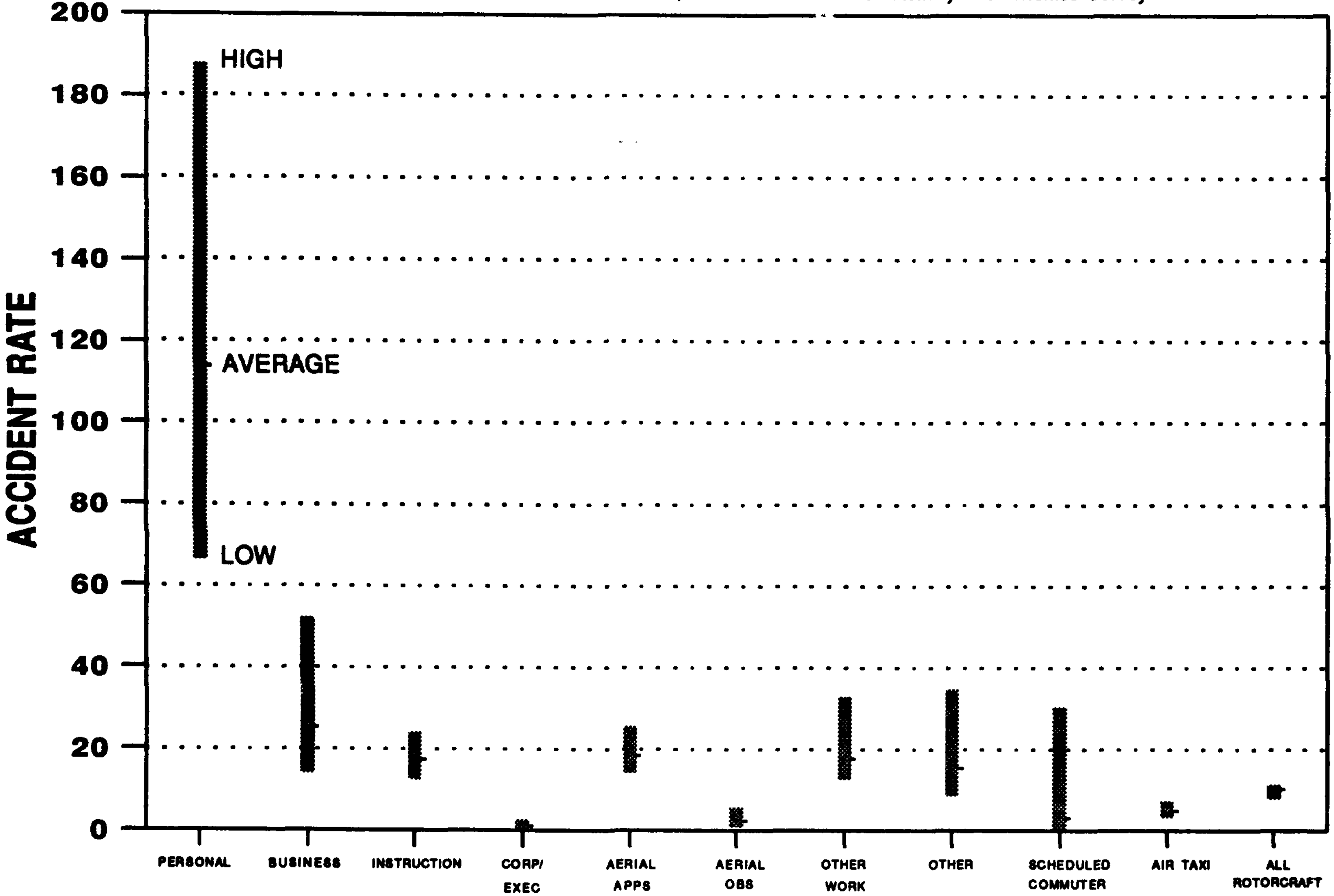
** Includes rental category

*** Percent standard error does not include rental category

Note: Column summation may differ from printed total due to estimation procedures.

Source: FAA General Aviation Activity and Avionics Survey, 1983 through 1986.

SOURCE: NTSB Accident Case Files; FAA General Aviation Activity and Avionics Survey



NOTE: As shown in table 10, the percent standard error of hours flown by individual mission types are high, indicating that the data is limited in accuracy. The percent standard error for the hours flown for the total fleet is low, indicating that these data are reliable.

FIGURE 9 ACCIDENTS PER 100,000 HOURS BY MISSION TYPE (1983 - 1986)

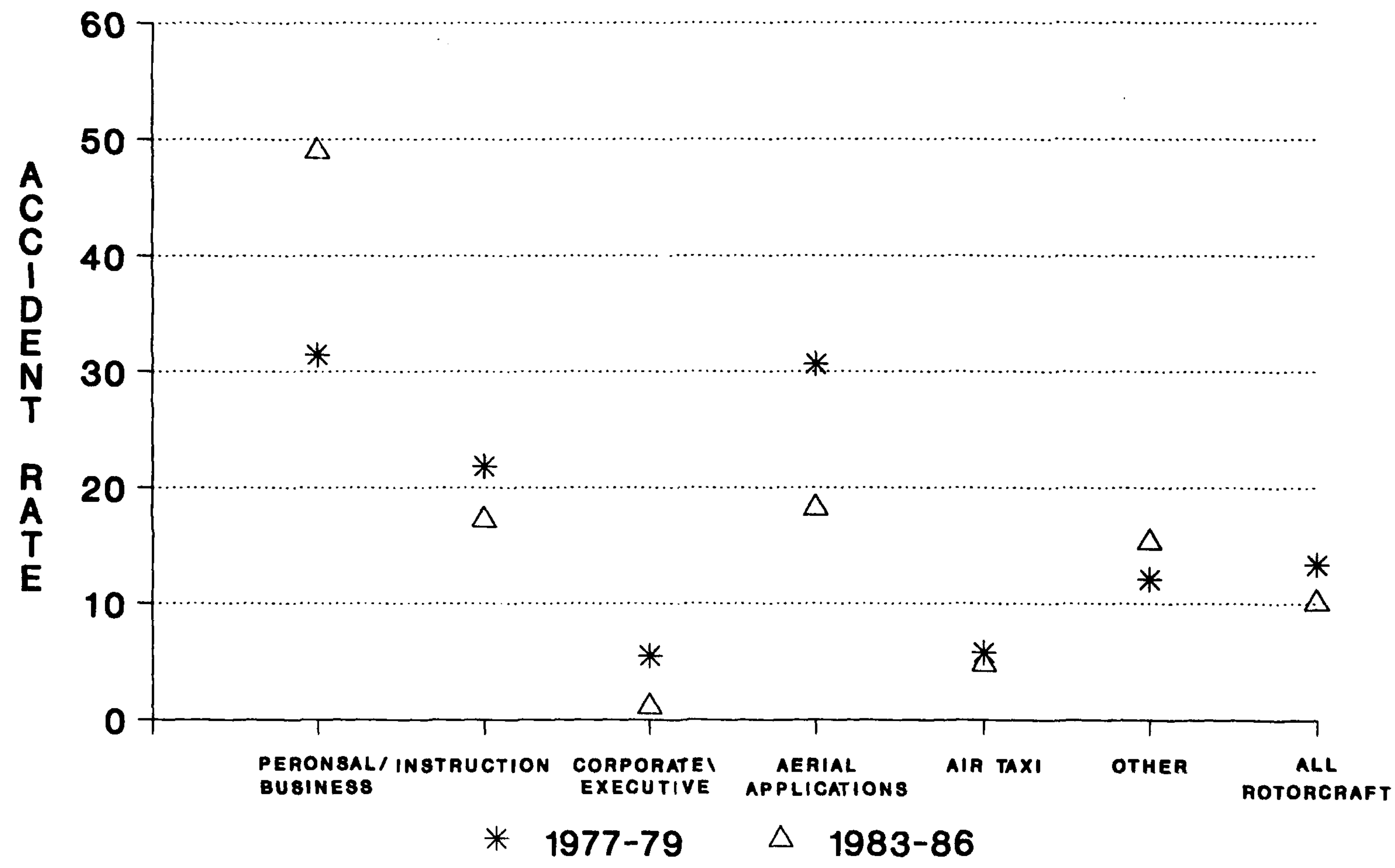


FIGURE 10 COMPARISON OF ACCIDENTS PER 100,000 HOURS FOR TWO TIME PERIODS, 1977 - 1979 AND 1983 - 1986

1989, NTSB records show that seven amateur-built helicopters were involved in accidents. Am- teur-built helicopters flew approximately 21,830 hours in 1989 (reference 33), for an accident rate of 32 per 100,000 hours. Although all seven aircraft were substantially damaged or destroyed, only one of the seven accidents involved any injuries.

4.2 FATAL ACCIDENT RATES BY HOURS FLOWN

From the NTSB case files for 1983 through 1986, fatal accident statistics were categorized by mission type. These data are presented in table 11. These data were also used with the operations data for the corresponding years to determine fatal accidents per 100,000 hours. These rates are shown in figure 11.

TABLE 11 HELICOPTER FATAL ACCIDENTS BY MISSION TYPE (1983-1986)

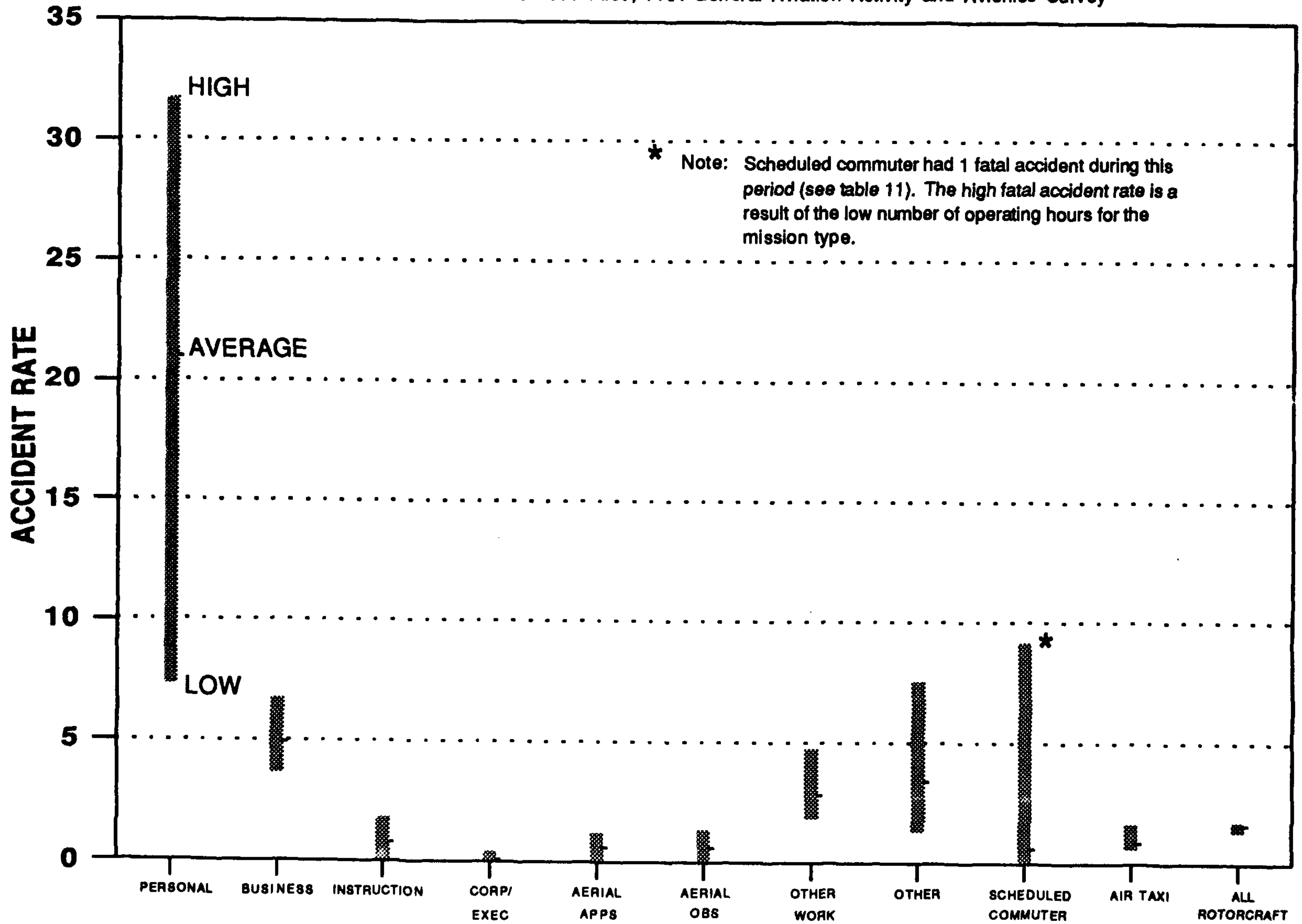
MISSION TYPE	1983	1984	1985	1986	Total
Personal	7	13	4	9	33
Business	4	4	7	6	21
Instruction	3	1	1	0	5
Corporate/Executive	0	1	0	1	2
Aerial Applications	1	0	1	5	7
Aerial Observation	1	0	2	6	9
Other Work	4	2	5	3	14
Other	9	11	9	4	33
Scheduled Commuter	0	0	1	0	1
Air Taxi	4	7	7	8	26
Total Helicopter	33	39	37	42	151

Source: NTSB Case Files

The fatal accident rates in figure 11 show both similarities and differences from the accident rates in figure 9. The "personal" and "business" categories show the same pattern of high rates compared to all rotorcraft. Similarly, the "corporate/executive," "aerial observation," and "air taxi" categories show low rates in the two figures. The two most interesting categories are "instruction" and "aerial applications." Although each showed higher than average accident rates compared to all rotorcraft, the fatal accident rate for each category is less than the average for all rotorcraft. It is of further interest to note that aircraft designated for "aerial applications" are required to have shoulder harnesses. Use of shoulder harnesses by aerial application pilots could account for increased accident survivability for this mission type. Note that by a recent change to the FAA regulations, all helicopters manufactured after September 16, 1992 are required to have shoulder harnesses at all seat locations.

Finally, the "scheduled commuter" category has an unexpectedly high number represented by the "HIGH" value. This "HIGH" value corresponds to one fatal

SOURCE: NTSB Accident Case Files; FAA General Aviation Activity and Avionics Survey



NOTE: As shown in table 10, the percent standard error of hours flown by individual mission types are high, indicating that the data is limited in accuracy. The percent standard error for the hours flown for the total fleet is low, indicating that these data are reliable.

FIGURE 11 FATAL ACCIDENTS PER 100,000 HOURS BY MISSION TYPE (1983 - 1986)

accident throughout the 4-year period. However, dividing this one fatal accident by a relatively low number of annual operating hours results in a rather high accident rate and should not be considered indicative of the relative safety for this mission type.

4.3 ACCIDENT RATE PER 100,000 MISSION SEGMENTS

This paragraph addresses accidents per 100,000 mission segments. For purposes of this report, a mission segment will be defined as a flight that involves one takeoff and one landing, regardless of the amount of time required to complete the flight. For instance, if a corporate/executive helicopter flies from New York to Washington, D.C. with one stop in Philadelphia, then that entire trip involves two mission segments.

In order to determine accidents per 100,000 mission segments, the average number of mission segments per hour for each mission type was estimated. The data source for this effort was taken from a special survey of all helicopter operators conducted for the FAA Office of Policy and International Aviation by the Applied Systems Institute and the Helicopter Foundation International. The data resulting from this survey and an analysis of the survey results are contained in reference 7. Although limited to a single year (1987), data from this survey present the best opportunity to determine typical mission segment lengths per flight hour. This approach was used to convert accidents (and fatal accidents) per 100,000 flight hours to accidents (and fatal accidents) per 100,000 mission segments. Table 12 presents a summary of the pertinent data from reference 7 and describes the analysis to determine mission segments per hour and mission duration.

TABLE 12 AVERAGE MISSION DURATION FOR 1987

Column No. PRIMARY USE	(1) HOURS FLOWN	(2) OPS* PER HELI	(3) FLEET SIZE	(4) ANNUAL NUMBER OPS*	(5) MISSION SEGMENTS (M.S.)	(6) M.S. PER HR.	(7) MISSION DURATION (MIN.)
Executive	117,556	1,426	305	434,930	217,465	1.85	32
Business	250,327	950	1,346	1,277,750	638,875	2.55	23
Personal	49,622	354	534	189,036	94,518	1.90	32
Instruction	117,108	541	352	190,432	95,216	0.81	74
Aerial App.	262,315	2,869	917	2,630,873	1,315,437	5.01	12
Work Use	1,173,271	1,339	2,328	3,115,853	1,557,927	1.33	45
Air Taxi	790,358	2,419	1,135	2,745,565	1,372,783	1.74	35
Other	113,129	2,133	207	441,531	220,766	1.95	31
Total	2,873,686		7,124	11,025,970	5,514,131		
				(weighted Average)		1.92	31

* Operations

Source: Columns 1 through 4, "Helicopter Forecasting Assessment," (ref. 7)
Column 5 = (column 4)/2; (1 operation = 1 takeoff or 1 landing)
Column 6 = (column 5)/(column 1)
Column 7 = (60 minutes/hour)/(column 6)

As shown in table 12, according to this survey, helicopter usage in 1987 totaled nearly 3 million hours flown with an average flight length of 31 minutes, or 1.92 mission segments per flight hour. Table 12 also shows that there is a wide variation in mission length by type of primary use. In fact, this parameter varies from a minimum of only 12 minutes for "aerial applications" to a maximum of 74 minutes for "instruction." It is therefore necessary to analyze each of the various missions to obtain a reasonable understanding of the risk exposure to be expected.

The mission segments per hour and the mission duration statistics were cross-checked with data from the FAA General Aviation Activity and Avionics Survey for the years 1985 through 1988. This survey shows a total of 20.45 million helicopter landings for these 4 years. In addition, this survey shows 10.36 million hours flown for these same 4 years. These data yield 2.01 mission segments per hour. This statistic is quite close to the average mission segments per hour (1.92) for all helicopters calculated in table 12. With this gross check of the mission duration estimates, these data were used to compute accidents and fatal accidents per 100,000 mission segments.

The accidents per 100,000 mission segments were calculated from the data in tables 9, 10, and 12. The results of this analysis are shown in figure 12. Most categories show patterns that are similar to the accidents per 100,000 hours. However, two exceptions are the "instruction" and "aerial applications" categories. Due to the very long mission durations of the "instruction" category, the accidents per 100,000 mission segments are higher relative to accidents per 100,000 flight hours. The opposite effect is shown for the "aerial applications" category. Because of this mission's very short average duration, the accidents per 100,000 mission segments for this category are lower, by comparison, relative to accidents per 100,000 flight hours.

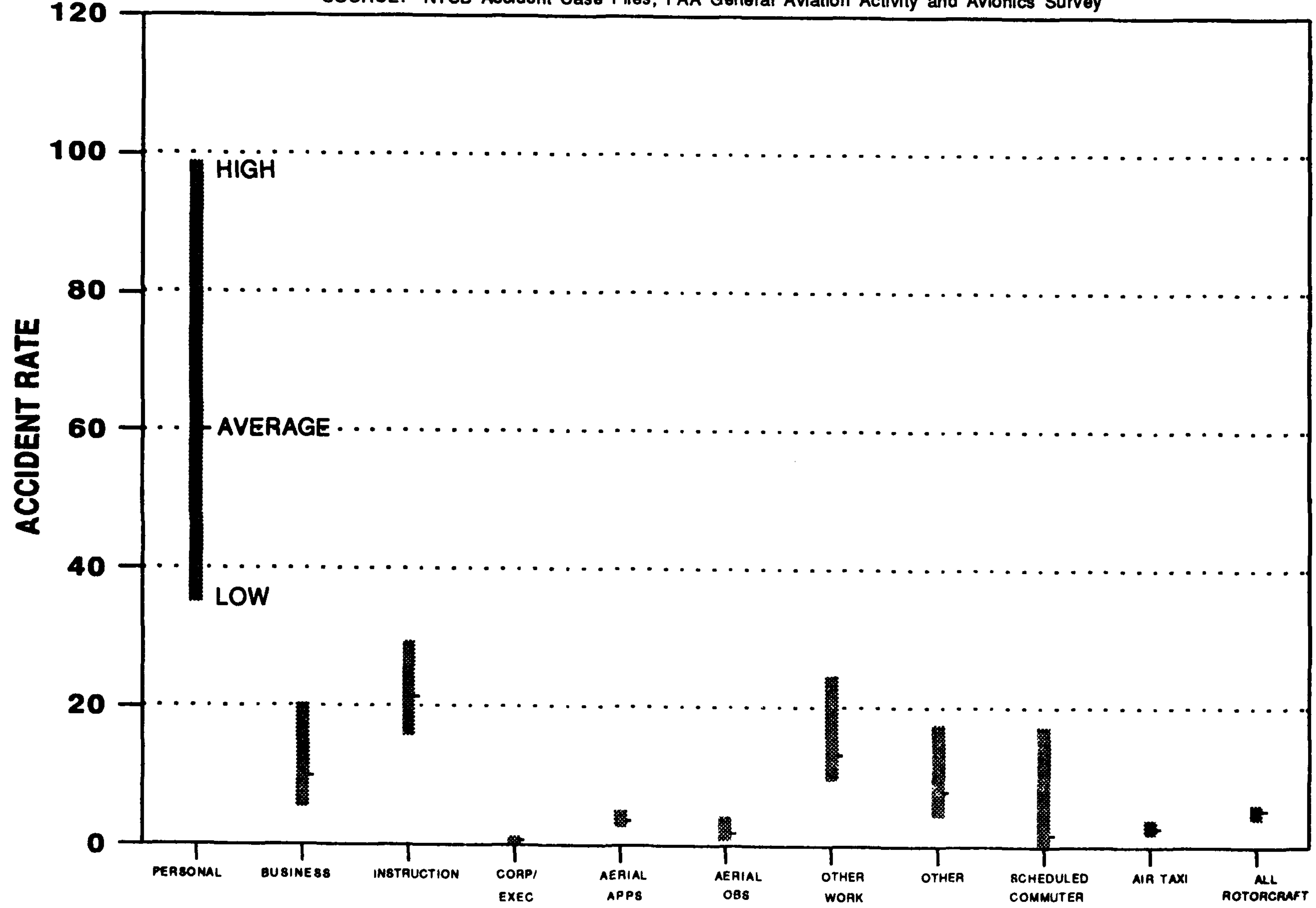
4.4 FATAL ACCIDENT RATES PER MISSION SEGMENT

The fatal accidents per 100,000 mission segments were calculated from the data in tables 10, 11, and 12. The results of the analysis are shown in figure 13. Again, the pattern is similar to the rates shown in prior graphs. The "personal" category has fatal accident rates that are an order of magnitude higher than most other categories. For the "aerial applications" category, the relatively low number of fatal accidents combined with the short duration of the flights produces very low fatal accidents per 100,000 mission segments. The rates for the other categories are similar in their relative magnitudes to the values shown in the prior figures.

4.5 HELICOPTER TO FIXED-WING ACCIDENT RATE COMPARISONS

Figures 14 through 17 present a comparison of helicopter and fixed-wing accident statistics based on accidents per 100,000 hours and per 100,000 mission segments. Appendix B contains a tabular listing of the information contained in figures 14 through 17. The accident rate data (figure 14) is identical to that presented in figure 5 for the corresponding period. The fatal accident rate data (figure 16) is identical to that presented in figure 7 for the corresponding period.

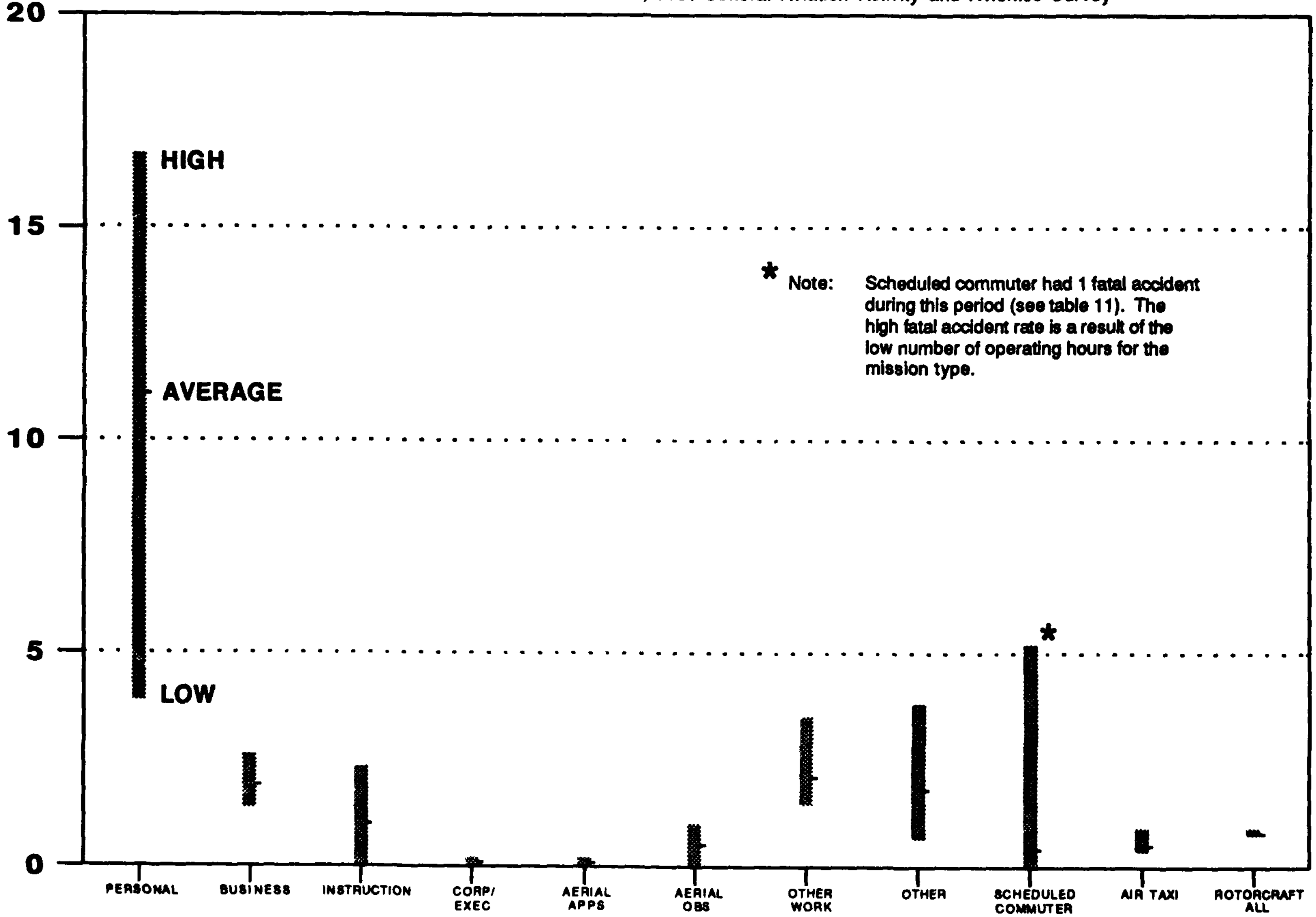
SOURCE: NTSB Accident Case Files; FAA General Aviation Activity and Avionics Survey



NOTE: As shown in table 10, the percent standard error of hours flown by individual mission types are high, indicating that the data is limited in accuracy. The percent standard error for the hours flown for the total fleet is low, indicating that these data are reliable.

FIGURE 12 ACCIDENTS PER 100,000 MISSION SEGMENTS BY MISSION TYPE (1983 - 1986)

SOURCE: NTSB Accident Case Files; FAA General Aviation Activity and Avionics Survey



NOTE: As shown in table 10, the percent standard error of hours flown by individual mission types are high, indicating that the data is limited in accuracy. The percent standard error for the hours flown for the total fleet is low, indicating that these data are reliable.

FIGURE 13 FATAL ACCIDENTS PER 100,000 MISSION SEGMENTS BY MISSION TYPE (1983 - 1986)

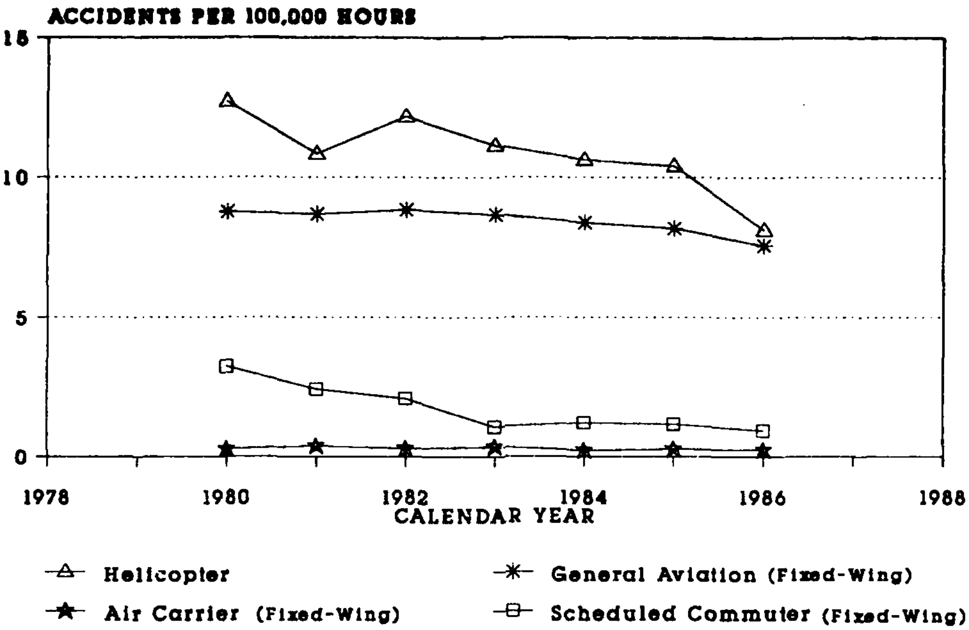


FIGURE 14 COMPARISON OF ANNUAL ACCIDENT RATES

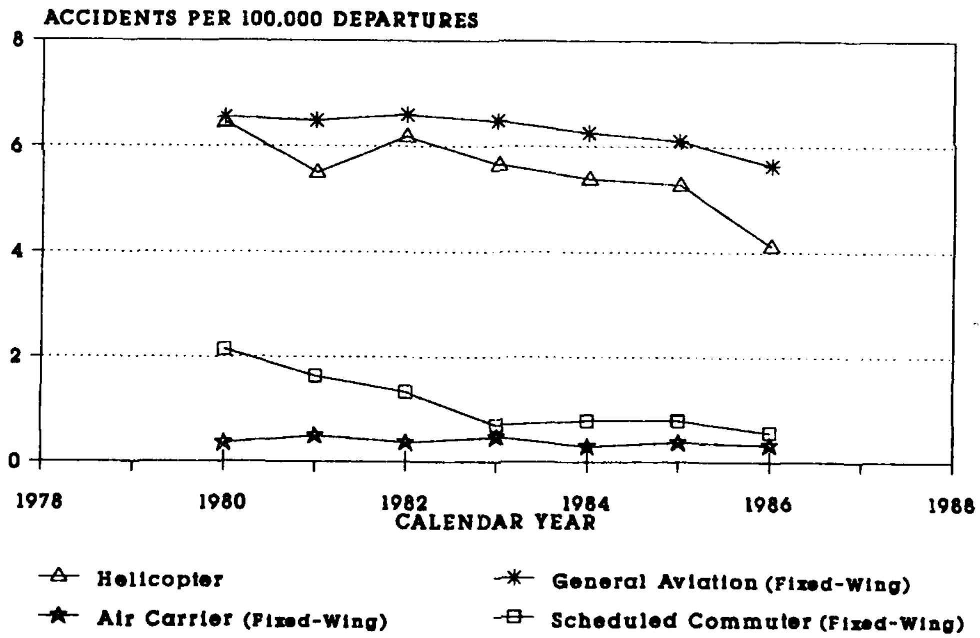


FIGURE 15 COMPARISON OF ANNUAL ACCIDENTS BY DEPARTURES

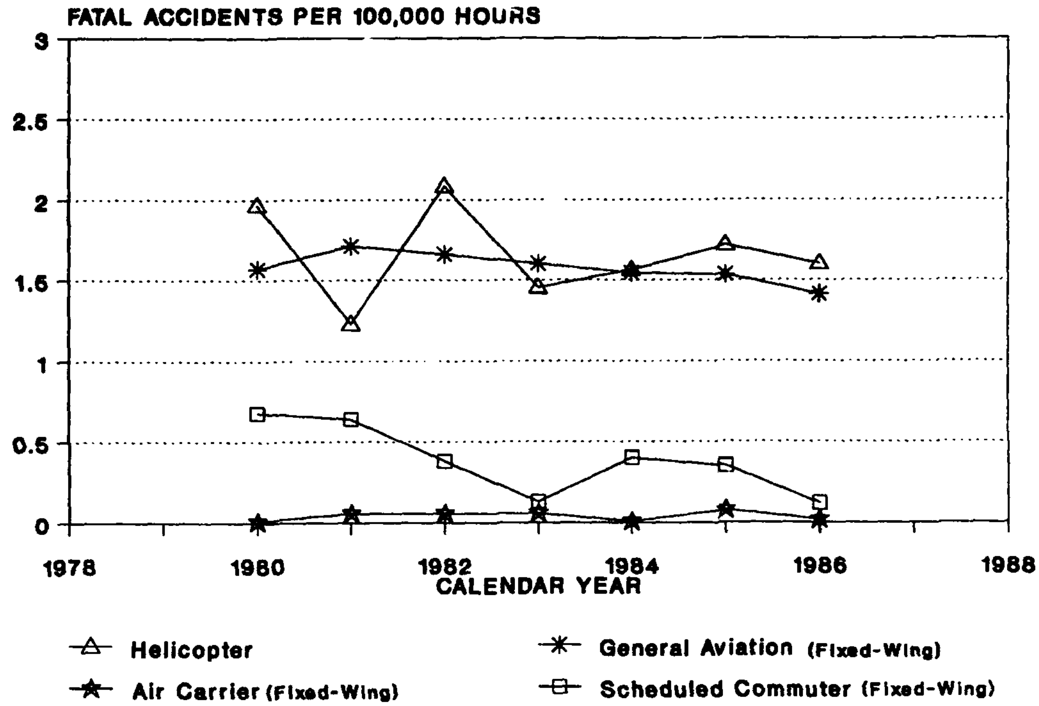


FIGURE 16 COMPARISON OF ANNUAL FATAL ACCIDENT RATES

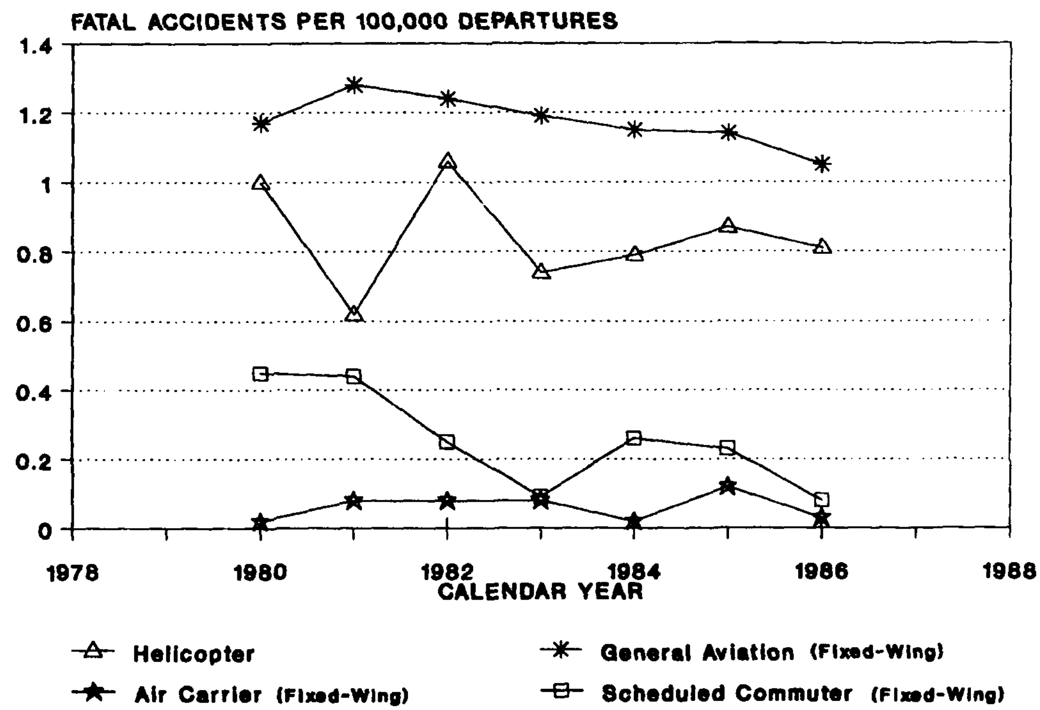


FIGURE 17 COMPARISON OF FATAL ACCIDENTS BY DEPARTURES

The number of mission segments per flight hour for helicopters (1.92) was taken from table 12. The number of mission segments per flight hour for general aviation (1.34) was based on flight hour and departure data contained in the 1985 and 1986 FAA General Aviation Activity and Avionics Survey (reference 19). The number of mission segments per flight hour for air carrier and scheduled commuter were calculated for each year from data in the NTSB annual air carrier review reports (reference 21). Figures 15 and 17 indicate that the risk of a helicopter accident or fatal accident is lower than that for general aviation fixed-wing aircraft when measured on a per mission segment basis.

The missions of helicopters and fixed-wing aircraft differ dramatically. Thus, comparing their respective accident rates is something of an "apples and oranges" comparison. The riskiest portion of any aircraft flight is during approach and departure. The average helicopter flight is much shorter than the average fixed-wing flight. Thus, helicopters spend a significantly larger percentage of their flight hours in the riskier phases of flight. In spite of this, the rotorcraft industry has improved their safety record over the years. In the mid-1960's, the helicopter annual accident rate was nearly twice that of general aviation fixed-wing aircraft. However, in the last several years, the helicopter accident rate has been equal to or below the general aviation fixed-wing rate (see figure 5). Tremendous progress has been made in reducing the helicopter accident rate.

5.0 HELIPORT/HELICOPTER OCCUPANT RISK EXPOSURE

5.1 RISK OF SERIOUS INJURY TO HELICOPTER OCCUPANTS

This section examines the risk exposure to helicopter occupants, including both passengers and crew members. As previously discussed, a variety of risk measures can be used as safety barometers depending on the intended application. Total accidents, accident rates, or fatal accident rates are not necessarily appropriate when trying to assess the potential for major injury or death, since they do not distinguish between the potential for fatalities as a function of the number of individuals that could be injured if an accident occurs. For this reason, Mr. Roy Fox, in his article entitled "Relative Risk: The True Measure of Safety" (reference 10), developed a technique to compare the percentage of occupants with fatal or major injuries to the total number of occupants exposed to potential harm. The parameter used for this analysis is defined as the relative risk of serious injury (RSI). RSI includes all major and fatal injuries that are referred to as serious injuries. Minor injuries are not included. RSI is the probability of being exposed to harm (accident rate), multiplied by the conditional probability of receiving a serious injury (i.e., the number of occupants seriously injured divided by the total number of occupants on board during the accident), given that an accident has occurred.

NTSB data for the 10-year period from 1977 to 1986 were reviewed to calculate RSI. Table 13 summarizes the raw data and presents RSI calculated for helicopter accidents at or within 1 mile of all landing sites (i.e., heliports, airports, remote sites, etc.). The RSI ratio represents the individual's relative risk of serious injury (fatal or major) per 100,000 occupant flight hours.

As shown in the table, the conditional probability of receiving a serious injury given that an accident occurred, the [(fatal + major)/total on board during the accident] ratio, varied from a high of 0.222 in 1979 to minimums of 0.077 and 0.097 in 1981 and 1983, respectively. This indicates that given one is an occupant of a helicopter and an accident occurs, the chance of serious harm ranged from 7.7 percent to 22.2 percent. Over a 10-year period (1977 to 1986), the helicopter occupant RSI average was 1.5 per 100,000 occupant hours. The RSI trend (see table 13) has shown very little improvement over the last several years.

5.2 RISKS ON THE GROUND

In addition to the occupant RSI, the risk to people and facilities on the ground was also examined. From the 1977-81 NTSB ground personnel injury data reports, it was determined that there were no off-facility property damage accidents within 1 mile of the landing sites during the 5 year period.

Tables 14, 15, and 16 present the summary data within 1 mile of landing sites for 1982 through 1986. Table 14 clearly shows the rarity of ground personnel injuries at airports. The table does show an occasional serious personnel injury at heliports, about one every other year. As might be expected, the

TABLE 13 RISK OF SERIOUS INJURY DATA AT ALL LANDING SITES

YEAR	(1)* FATAL INJURY	(2)* MAJOR INJURY	(3) FATAL & MAJOR	(4)* TOTAL OCCUPANT	(5) (FAT+MAJ)/ TOTAL	(6)** ACCIDENTS/ 100,000 HRS	(7)*** RSI/100,000 OCCUPANT HOURS
1977	5	14	19	174	0.109	14.46	1.58
1978	7	19	26	200	0.130	13.78	1.79
1979	14	24	38	171	0.222	10.88	2.42
1980	22	11	33	196	0.168	12.70	2.13
1981	0	13	13	169	0.077	10.84	0.83
1982	9	11	20	165	0.121	12.17	1.47
1983	5	19	24	248	0.097	11.14	1.08
1984	13	22	35	250	0.140	10.62	1.49
1985	9	14	23	177	0.130	10.35	1.35
1986	6	20	26	156	0.167	8.11	1.35
TOTAL	90	167	257	1,906	0.136 ****	11.51 ****	1.56 ****

* NTSB Accident Records

** Table 3

*** (Column 5)*(Column 6)

**** Weighted average based on 10 year total values.

TABLE 14 GROUND PERSONNEL INJURIES (ACCIDENTS WITHIN 1 MILE) FATAL PLUS MAJOR INJURIES

YEAR	HELIPORT	AIRPORT	REMOTE	UNKNOWN SITE	TOTAL
1982	1	0	0	1	2
1983	0	0	2	0	2
1984	1	0	0	2	3
1985	0	0	0	0	0
1986	1	0	6	1	8
TOTAL	3	0	8	4	15

TABLE 15 DAMAGE TO BUILDINGS, VEHICLES, AND PROPERTY WITHIN 1 MILE OF ALL LANDING SITES

YEAR	RESIDENCE(1)	COMMERCIAL BUILDING	VEHICLES	RESIDENTIAL AREA (2)	TOTAL
1982	0	1	0	0	1
1983	1	3	5	1	10
1984	3	4	4	2	13
1985	1	0	5	2	8
1986	1	4	8	2	15
TOTAL	6	12	22	7	47

(1) Residential buildings

(2) Residential property other than buildings

TABLE 16 DEPARTURE/APPROACH RISK EXPOSURE WITHIN 1 MILE OF LANDING SITES

YEAR	RESIDENCE (1)	COMMERCIAL BUILDING	VEHICLES	RESIDENTIAL AREA (2)	TOTAL
	Dep/App	Dep/App	Dep/App	Dep/App	Dep/App
1982	0/0	0/0	0/0	0/0	0/0
1983	0/0	2/0	1/1	0/0	3/1
1984	0/0	0/1	0/0	0/0	0/1
1985	1/0	0/0	0/0	0/0	1/0
1986	0/0	0/0	1/0	0/0	1/0
Total	1/0	2/1	2/1	0/0	5/2

(1) Residential buildings
(2) Residential property other than buildings

remote site data was slightly more risky, with eight personnel being seriously injured for the 5 years indicated. The risk of serious injury to ground personnel (both on-site and residential) was 0.12 per 100,000 hours averaged over the 5 years shown in table 14.

Similarly, table 15 lists collisions with objects at landing sites. These occurred somewhat more frequently; however, there were still relatively few such occurrences in any given year.

Finally, table 16 gives risk exposure data for operations on the approach and departure flight path. It can be seen that these occurrences are very infrequent.

In order to put these helicopter/heliport risks in perspective, the National Safety Council's "Accident Facts" (reference 11) showed that:

1. an accident happens every 4 seconds, an accidental death occurs every 6 minutes, and

2. every 12 minutes, a person dies in a motor vehicle accident.

On a broader transportation basis, the annual report, National Transportation Statistics, from the Department of Transportation (reference 12) showed the following fatalities by mode for the year 1984:

HIGHWAY	44,373
RAIL	653
AIR	1,211
MARINE	1,176
OTHER	35
TOTAL TRANSPORTATION	47,448

An unsuccessful attempt was made to normalize these numbers using revenue passenger miles, annual hours, or some other parameter. However, no common parameter was available for all modes. The major point of looking at these

very large numbers of deaths was to put helicopter risk of serious injury into proper perspective. As previously discussed in section 2.0 and shown in table 3, helicopter accident fatalities have averaged only 58 per year for the past 26 years.

5.3 NEIGHBORHOOD RISK EXPOSURE

A final way of looking at heliport risk is to analyze the risk to persons and things in the area surrounding the heliport (within 1 mile), a risk we have labeled "neighborhood risk." While others have developed elaborate formulas for calculating neighborhood risk, the following analysis will utilize only those assumptions and statistics previously used in this report for risk calculation.

One approach for determining risk to the neighborhood is based on the overall helicopter accident rate (10.1/100,000 hours average for the years 1983 to 1986 from table 3 and figure 10) for all helicopter operations, and the percentage of time estimated to be spent over the neighborhood during normal operations. This results in a determination of the average amount of time (in years) that would pass before an accident occurs over the neighborhood. This average time period is estimated by the following formula (equation 1):

$$\frac{1}{\text{(Missions/year)} \times (.05\ \text{hr/mission}) \times (\text{Accidents}/100{,}000\ \text{hrs})} = \text{Years/Accident} \quad (1)$$

The purpose of the formula is to determine, based upon the number of annual helicopter missions at a given landing site, how long it will take to accumulate 100,000 hours of operations. If statistically 10.1 accidents occur per 100,000 hours, then on the average when 100,000 hours have accumulated within 1 mile or at a given landing site, 10.1 accidents should have occurred. For purposes of this exercise, it is assumed that 3.5 minutes of each flight are spent on arrival and departure (1.5 minutes for departure, 2.0 minutes for approach). Because some portion of that time is spent over the heliport, it is assumed for this analysis that 3 of the 3.5 minutes are spent over the neighborhood. As used in equation 1, the 3 minutes per mission in the vicinity of the neighborhood is stated as 0.05 hours. When inserting the number of missions per year (the example uses 400 missions per year), the formula yields neighborhood risk in terms of projected average years between accidents.

$$\frac{1}{(400\ \text{missions/yr}) \times (.05\ \text{hours/mission}) \times (10.1\ \text{accidents}/100{,}000\ \text{hrs})} = 495\ \text{Years/Accident}$$

Therefore, if there are 400 missions flown annually from a given heliport, the average likelihood of an accident over the neighborhood (within 1 mile of the heliport) is one accident in 495 years.

When coupled with the additionally remote probability that anyone on the ground is injured (see section 5.2) if/when an accident does occur, a heliport and its associated operations are statistically a very low risk to neighborhood residents and property.

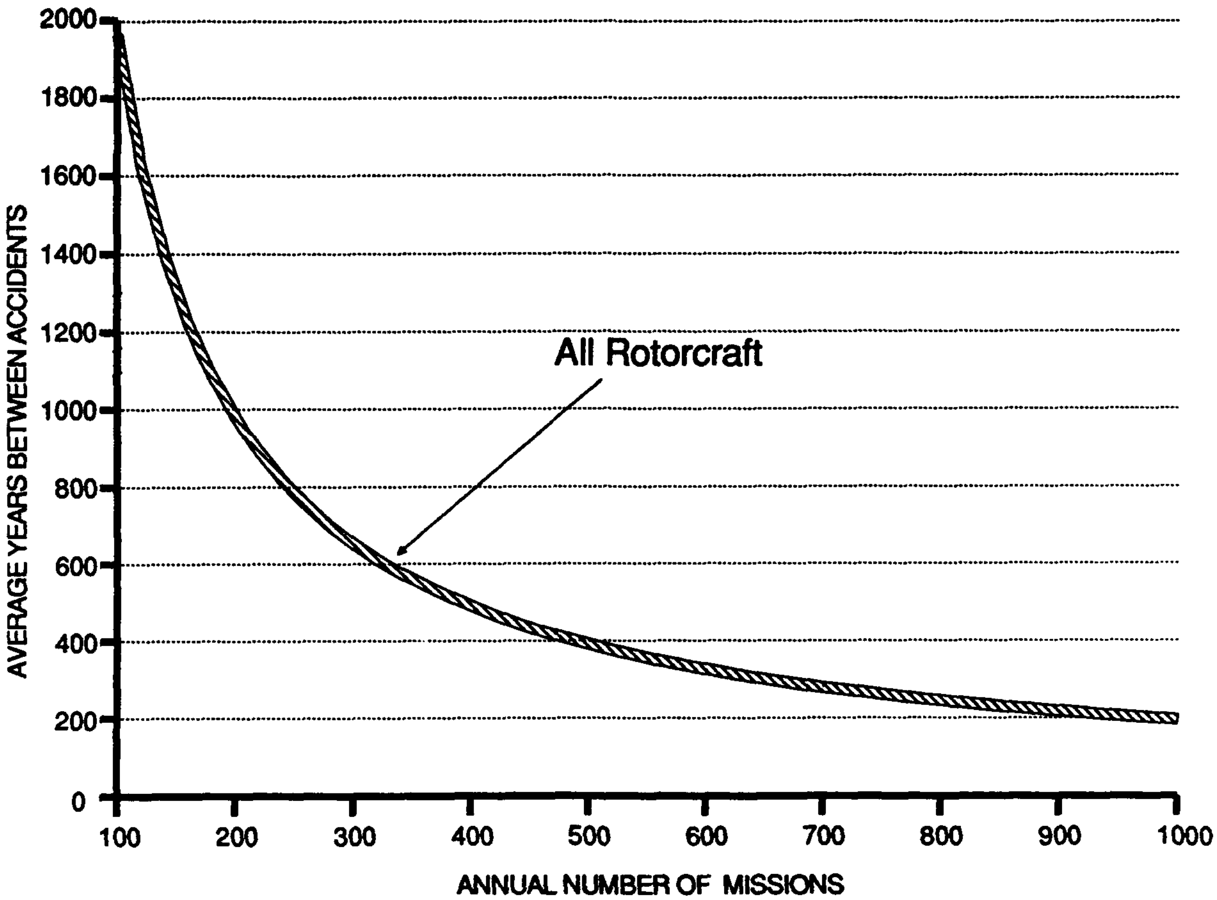


FIGURE 18 NEIGHBORHOOD RISK EXPOSURE BY MISSION

NOTE: This figure is based on the helicopter accident rate during the 1983 to 1986 time period. It should be noted that, in the years since 1986, the helicopter accident rate has continued to improve (see figure 19).

6.0 PROJECTED ACCIDENT RATES AND TARGET LEVELS OF SAFETY

Up to this point, this report has analyzed and discussed a number of safety indicators, risk exposure parameters, and accident barometers. However, it would be incomplete to stop now without interpreting what this means. This section uses the historical accident trends as a decisionmaking tool.

Even though travel by air is one of the safest modes of transportation, the public demands that continuing efforts be directed at further reducing accident rates (see reference 31). The rotorcraft industry needs to be particularly attentive to these demands. Rotorcraft accident rates have dropped significantly, as shown in figure 5. In addition, rotorcraft accident rates compare favorably with those of fixed-wing aircraft. Still, a significant portion of the public perceives rotorcraft as being unsafe. If rotorcraft are to be better accepted by the public, operators need to improve their safety record on a continuing basis.

Safety is a relative term. In most situations, one can choose to do things in a way that would lead to safer operations. However, the increase in safety might be vastly overwhelmed by the increase in cost. How should the rotorcraft community continue in their efforts to improve the safety of helicopter operations? One approach is to identify the issues that are leading to accidents/mishaps, to rank them in order, to address the more significant issues, and to decide what steps should be taken to reduce the related accidents/mishaps. The target level of safety (TLOS) concept can be a valuable tool in this process. This concept is of particular interest in defining minimum design requirements (such as minimum VFR heliport airspace during curved approaches and departures). A TLOS provides an objective way of taking a safety goal and translating it into design requirements.

The first discussion of the use of the TLOS concept with regard to rotorcraft is contained in reference 32. Building on this earlier effort, this document develops and proposes specific target levels.

6.1 HISTORICAL APPROACHES TO DEFINING TARGET LEVELS

Historically, two different approaches have been used for deriving a specific target level of safety. The first is a comparison of aviation risk with the risk levels associated with non-aviation activity. The three specific bases used for setting target levels in this approach are:

1. compare air transportation safety statistics with surface public transportation safety statistics (total accidents/passenger mile, fatalities/passenger mile),

2. compare passenger mortality rates in aircraft with population mortality rates due to all causes (fatalities/year), and

3. compare aircrew occupational risk of accidental death with other occupations (pilot fatalities/year as compared to other occupations).

The second approach is to determine target levels based on past performance in aviation safety. The basis used in this approach is:

4. compare past improvements in aviation accident rates with a target factor for future improvements.

In "Target Levels of Safety for Controlled Airspace" (reference 16), the CAA compared levels of safety using these four different bases. The results showed that each of the four values obtained were of the same general order of magnitude. Therefore, the comparison with past performance in the field of aviation (basis item 4) was selected as most appropriate. This approach requires two important choices:

1. the period and aviation environment which represent historical safety levels, and

2. the size of the target improvement factor.

6.2 HELICOPTER ACCIDENT RATES AND PROJECTED IMPROVEMENTS

The reference period selected as representative for the analysis was the period 1964 through 1989. This period covers: 1) the mature activity of piston helicopters, up to about 1980, when they represented approximately 50 percent of the fleet; 2) the emergence and growth of the turbine helicopter; 3) the increasing use of sophisticated twin engine helicopters; 4) the emerging demand for heliports; and 5) periods of both growth and decline in helicopter utilization rates. For these reasons, the accident rates associated with this period and environment provide a reasonable statistical foundation for projecting safety levels through the 2000 time frame.

Figure 19 illustrates the historical trend for annual helicopter accidents per 100,000 flight hours. Fixed-wing accident rates are also included for comparison. Since the rate shows a trend for helicopters that has dropped continually and dramatically over the period, a reasonable projected improvement is to sustain the improvement demonstrated between 1979 and 1989. An exponential trend line for this period was fit to the helicopter accident rate data. An annual improvement factor of 6.30 percent was computed. The trend line produces a helicopter accident rate of 3.6 accidents/100,000 hours in the year 2000. Although a factor of four greater than that of air carriers, this rate is dramatically reduced when compared to previous decades.

As a further cross-check, a rate of 3.6 accidents/100,000 hours can be converted to annual total accidents. Since annual operating hours have remained fairly steady for the 1986 to 1989 period, an average of 2.725 million hours flown would mean that about 98 accidents would be expected in the year 2000. Based on the 185 accidents in 1989, the projection indicates a reduction in total accidents of 87, or 47 percent. This appears to be an aggressive, yet achievable projection based on recent trends.

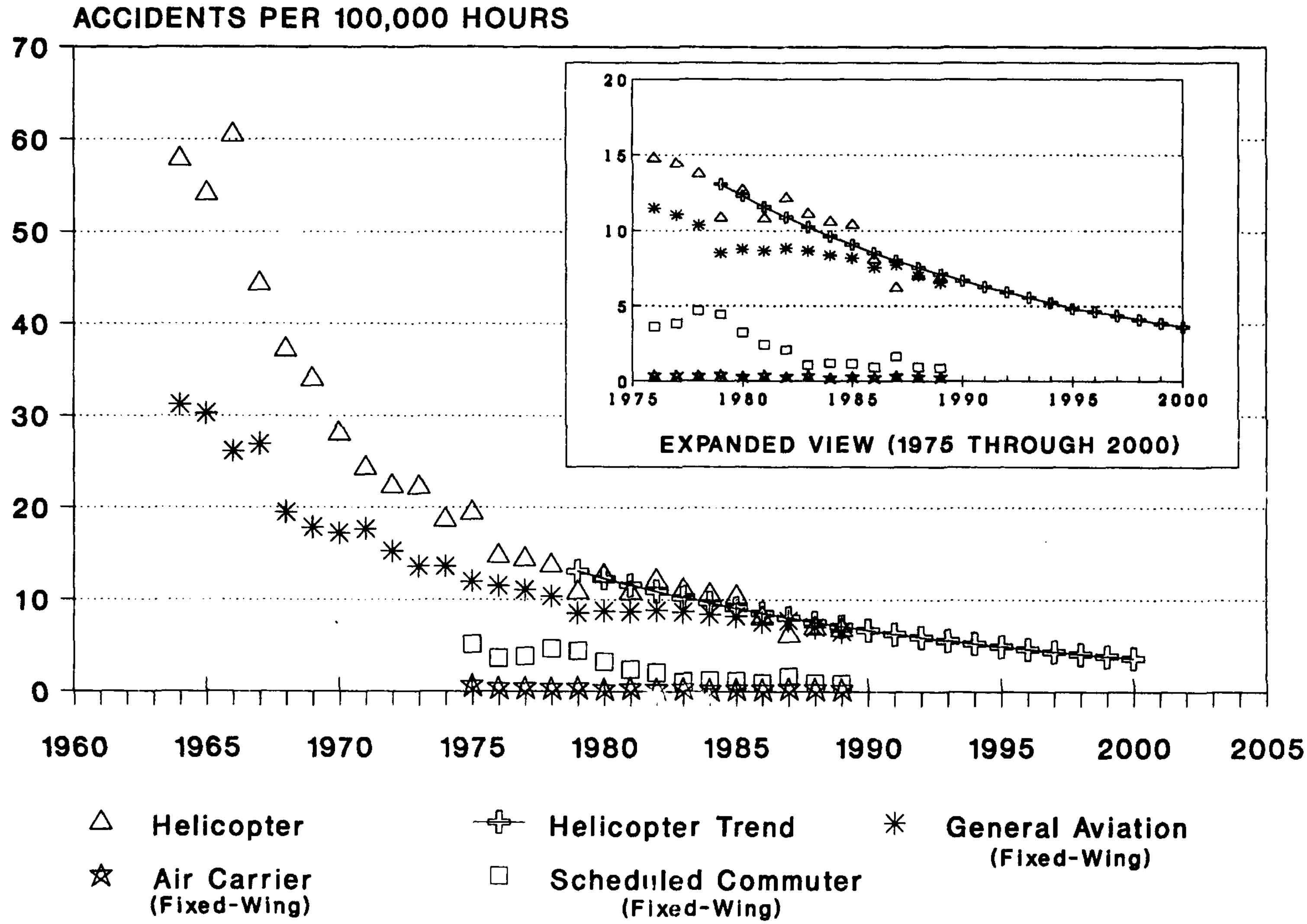


FIGURE 19 HELICOPTER ACCIDENT RATES AND PROJECTED IMPROVEMENTS

6.3 HELICOPTER FATAL ACCIDENT RATES AND PROJECTED IMPROVEMENTS

A similar analysis was performed to establish projected fatal helicopter accident rates. Figure 20 shows the historical helicopter trend over the 1979 through 1989 time period for this safety parameter. The exponential trend line in figure 20 shows an annual improvement factor of 4.23 percent. The trend line produces a fatal accident rate of 0.7 fatal accidents per 100,000 hours in the year 2000. Assuming that the operating hours remain constant at 2.725 million hours flown, the projection indicates that about 19 fatal accidents would occur in the year 2000. Again, this appears to be an aggressive, yet achievable, projection based on recent safety data and represents dramatic improvement when compared to previous decades.

6.4 TAKEOFF/LANDING AND GROUND OPERATIONS ACCIDENT RATES AND PROJECTED IMPROVEMENTS

The projected accident rate analysis also applied to takeoff/landing accidents and to ground/hover/taxi accidents. The helicopter and general aviation data used as a basis for this analysis were derived from NTSB files of aircraft accident data, for calendar years 1977 through 1986. As described in section 3.1 of this report, these NTSB reports contain analysis of accidents by phase of flight. Table 5 in section 3.1 describes the flight phases that were included in the analysis of accidents in the vicinity of heliports, airports, and unimproved landing sites. These flight phases are: standing, taxi, takeoff, approach, landing, and hover. These accidents were subdivided into two groups as follows:

Ground Operations - standing/hover/taxi
Takeoff/Landing - takeoff/approach/landing

The analysis proceeded using the same methodology as described in section 3.1. The resulting helicopter accident counts, as well as fixed-wing general aviation, air carrier, and scheduled commuter accident counts, are provided in appendix C.

The accident rates for this analysis are based on a per takeoff/landing, or per ground operation basis. The number of helicopter and general aviation annual takeoffs and landings was estimated by dividing the annual number of hours flown by the average number of landings per hour. Since 1985, the number of landings has been estimated by the FAA and reported in the annual General Aviation Activity and Avionics Survey. Prior to 1985, data on the number of landings was not requested on the FAA survey form. The survey data shows that, for the years 1985 through 1988, an average of 2.01 landings per flight hour were performed by rotorcraft. The number of general aviation landings was computed from 1985 and 1986 and showed 1.34 landings per flight hour. These values were used to convert the annual hours flown to annual landings. The approach and departure data for air carrier and scheduled commuters was obtained from the "Annual Review of Aircraft Accident Data, U.S. Air Carrier," for the appropriate years. The takeoff/landing accident numbers were computed as the sum of the takeoff and landing accidents. The number of takeoff/landing operations as well as the number of ground operations were computed as the sum of takeoffs and landings. These data are shown in appendix D.

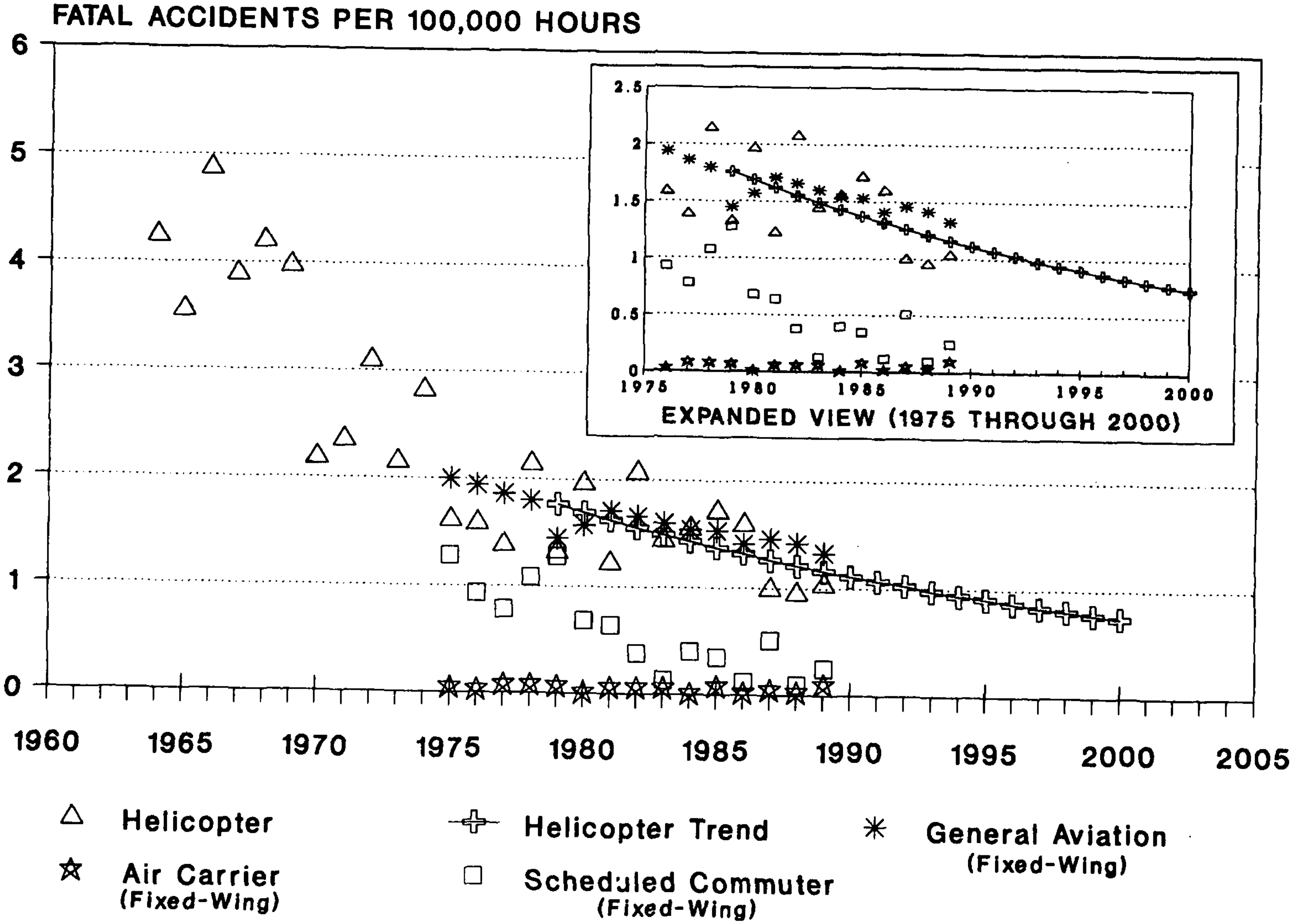


FIGURE 20 HELICOPTER FATAL ACCIDENT RATES AND PROJECTED IMPROVEMENTS

Annual accident rates for the takeoff/landing and ground operations categories were calculated from appendices C and D. The results are shown in figures 21 and 22. An exponential trend line was calculated for the helicopter takeoff/landing approach accident rate. The accident rate trend line showed an annual decrease of 8.5 percent. This projection, although representative of the improvement in recent years, seems overly optimistic. Therefore, the improvement rate was limited to 5.0 percent per year and produced a rate of 3.8 accidents per million takeoffs/landings for the year 2000.

The ground operations accident rate showed an unexpected and rather unsettled trend. The helicopter rate is significantly higher than that for comparable fixed-wing operations and it has been fluctuating. Because the trend is unsettled, it is not possible to project an accident improvement rate for the year 2000 using the same approach that was used for the takeoff/landing rate. Therefore, a projection of 3.0 ground/hover/taxi accidents per 100,000 operations is suggested for the year 2000. This would bring the accident rate back to the lowest rate that was observed in the study period, 1979.

Several important observations can be made from figures 21 and 22. First, the helicopter accident rate per million takeoff/landing is lower than the general aviation fixed-wing rate for the 7-year period analyzed. This is true in spite of the inherent risks of helicopter low altitude operations to remote and unimproved landing sites.

Second, the rate of helicopter accidents per million takeoff/landings has steadily decreased, as shown by the trend line in figure 21. In fact, this figure shows about a 40 percent reduction in accidents per million operations for the 1977 through 1986 time period.

Third, the ground/hover/taxi accident rate for helicopters is about one-half of that for either the approach/landing or takeoff/departure flight phases. However, this rate is significantly higher than that for comparable fixed-wing operations and it has been growing since 1981. There are several reasons that may explain the higher helicopter accident rate compared to the fixed-wing rate. The pilot work load during a helicopter hover/taxi is greater than that for a fixed-wing taxi operation. The fixed-wing pilot basically can focus attention in the direction of the taxi and ensure that the wings do not strike an obstruction. However, helicopters may hover/taxi in any direction including sideways and backwards which requires heightened awareness by the pilot. A pilot operating a helicopter must also guard against hitting an object with the landing gear, which could result in a dynamic rollover. Another reason for the higher helicopter rate may be the fact that an airplane wing strike to an obstacle may cause minimal damage and may not be reported as an accident. However, a turning helicopter main or tail rotor striking an obstacle is more likely to be a significant event and to be reported as an accident. Finally, many helicopter operations occur at remote locations, whereas most fixed-wing operations occur at established airports. The remote site operations are more demanding in terms of pilot workload than operations at established airports. The helicopter mishap analysis report (reference 6) discusses the types of objects that have been struck at various landing sites and provides recommendations on ways to mitigate these obstacle strikes.

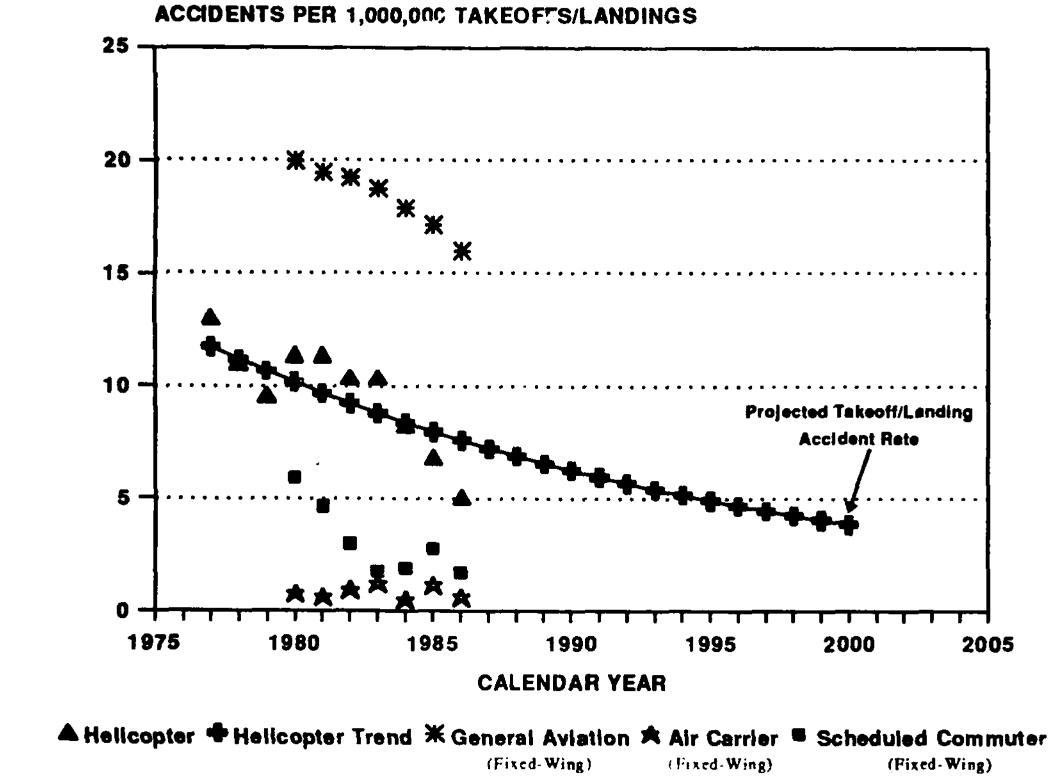


FIGURE 21 TAKEOFF/LANDING ACCIDENT RATES AND PROJECTED IMPROVEMENTS

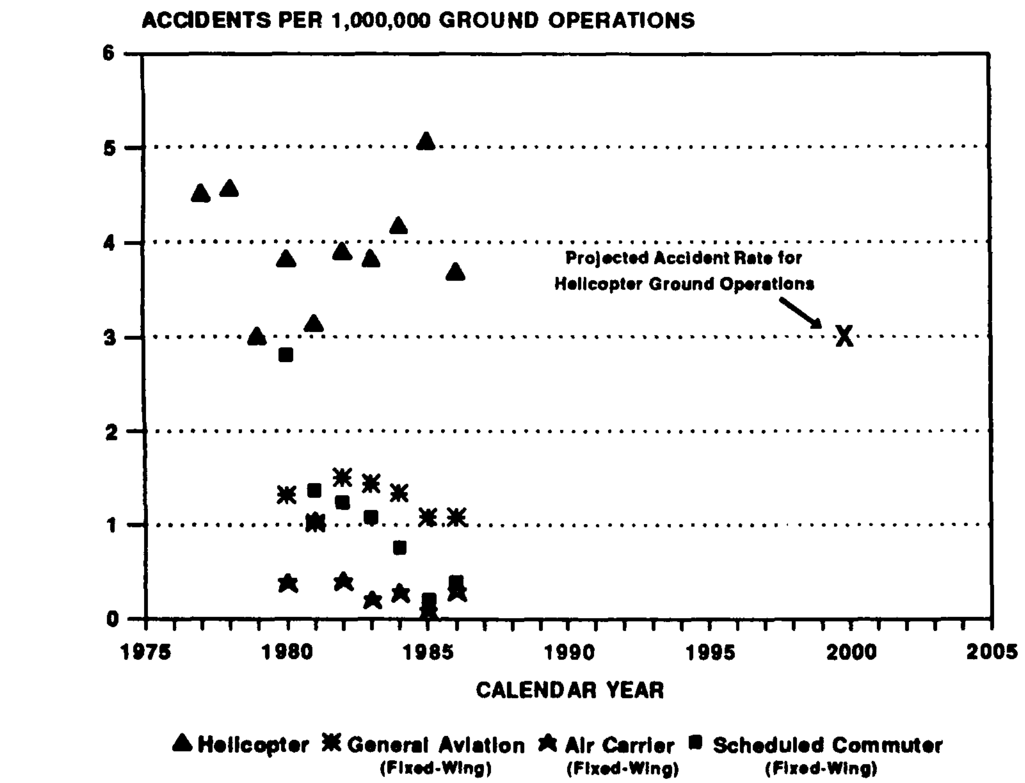


FIGURE 22 GROUND/HOVER/TAXI ACCIDENT RATES AND PROJECTED IMPROVEMENTS

6.5 ESTIMATE OF LANDING SITE DESIGN RISK

A companion report to this study entitled "Analysis of Helicopter Mishaps at Heliports, Airports, and Unimproved Sites" (reference 6), reviewed landing site mishaps in which landing site design may have been a major factor in the mishaps. The study involved both civil and military helicopter mishaps at heliports, airports, and unimproved landing sites. This section uses the results of the referenced study and determines a first-order estimate of helicopter risk exposure due, at least in part, to landing site design. The intention here is to relate landing-site-design risk exposure to civil helicopter operations. Although military helicopter operations do occur at civil facilities, only the civil mishaps from the companion report are employed to determine this risk exposure.

Table 17 presents the number of facility design-related accidents by year and facility type for the civil helicopter mishaps used in the mishap analysis study.

The 1987 through 1989 data set were only partial data sets and did not include all of the mishaps for those years. The mishap analysis report addresses the selection process and limitations encountered in mishap selection. Because of the limitations in selecting the appropriate mishaps for review, the risk exposure calculated below is limited to the years 1982 through 1986. Furthermore, limitations in the selection process could have caused some mishaps to be missed; for this reason the data can only be considered a first-order approximation of the number of design-related mishaps. Table 18 presents a first-order approximation of the risk exposure due to landing site design.

TABLE 17 FACILITY DESIGN-RELATED ACCIDENTS BY YEAR AND LANDING SITE TYPE

Year	Heliport	Airport	Unimproved	Total	Total Helicopter Accidents
1978	1	2	0	3	308
1979	2	1	0	3	280
1980	2	2	0	4	302
1981	3	2	0	5	291
1982	3	0	1	4	289
1983	5	3	2	10	253
1984	4	2	2	8	265
1985	7	1	2	10	224
1986	4	1	3	8	213
1987*	3	1	1	5	179
1988*	1	0	1	2	190
1989*	0	1	0	1	185
Total	35	16	12	63	2,979

*For the years 1987 through 1989, complete accident reports were not available for some accidents. For those accidents not having complete reports, the allocation of accidents to heliports, airports, and unimproved sites is based on data from the preliminary accident reports.

TABLE 18 LANDING SITE/HELIPORT DESIGN-RELATED RISK EXPOSURE*

Year	Total Helicopter Accidents	Landing Site Design-Related Accidents	Percent Landing Site Design-Related Accidents	Heliport Design-Related Accidents	Percent Design-Related Accidents at Heliports
1982	289	4	1.4	3	1.0
1983	253	10	3.9	5	2.0
1984	265	8	3.0	4	1.5
1985	224	10	4.5	7	3.1
1986	213	8	3.8	4	1.9
Total	1,244	40		26	
Average			3.2		2.1

* first-order approximation

Within the limitations described, table 19 shows that the percentage of landing site design-related accidents is less than 5 percent per year and averages slightly more than 3 percent per year. The percentage at heliports is 3 percent or less per year and averages slightly more than 2 percent per year. As noted in the mishap analysis report (reference 6), many (approximately 70 percent) of the mishaps studied occurred at landing sites that were not designed in accordance with the Heliport Design Advisory Circular (reference 15). Therefore, the number of landing site design-related accidents that occur at landing sites designed in accordance with the Heliport Design Advisory Circular is probably less than 2 percent of the total number of helicopter accidents per year and near 1 percent per year at heliports. In order to determine this number more accurately, a more in-depth study employing accident investigation techniques would be required.

6.6 TARGET LEVEL OF SAFETY: LANDING SITE AND HELIPORT DESIGN-RELATED ACCIDENT RATES

By combining the projected accident rates for takeoff/landing and ground operations developed in section 6.4 with the landing site/heliport design-related risk exposure developed in section 6.5, it is possible to develop a first-order approximation of the target levels of safety for landing site/heliport design-related accident rates. This is accomplished by multiplying the projected accident rates by the appropriate design risk percentage to produce the design-related target level of safety. The results of this process are shown in table 19.

TABLE 19 DESIGN-RELATED TARGET LEVELS OF SAFETY (TLOS)

	Projected Accident Rate (Year 2000)	Design-Related Percentage of Accidents at All Landing Sites	Design-Related Percentage of Accident at Heliports	Landing Site Design TLOS	Heliport Design TLOS
Takeoff/Landings	3.8/1*	3.2%	2.1%	1.2/10*	0.8/10*
Ground Operations	3.0/1*	3.2%	2.1%	1.0/10*	0.6/10*

* Million

6.7 SAFETY HORIZONS

Aeronautical decisionmaking (ADM), pilot decisionmaking (PDM), and judgement training are all terms used for the same approach to reducing human error-caused accidents. FAA research into this new area has yielded 10 reports (references 1, and 22 through 30). The primary helicopter report is "Aeronautical Decision Making for Helicopter Pilots," DOT/FAA/PM-86/45 (reference 26). No FAA report can have any effect on future accidents unless the information is applied by the industry. Early FAA studies predicted a 10 percent to 50 percent reduction in human error accidents if ADM were used. The following are promising signs of safety improvements in the reduction of human error accidents.

One of the largest U.S. civil helicopter operators who operates primarily in the Gulf of Mexico introduced judgment training into their in-house training courses. They report that they have been able to cut their accident rates in half. One United States helicopter manufacturer has introduced judgment training as part of their safety program. This includes safety training in their pilot ground school and safety training at customer and regional safety seminars. As a result, for their most popular model, the worldwide accident rate due to human error has been reduced by 36 percent over the last 4 years, as compared to the previous 4 years. Another United States manufacturer has also developed a software program that allows an individual pilot to use a personal computer as a pilot decision simulator (e.g., individualized judgment training). Starting in April 1991, the Canadian Government now requires PDM as part of a pilot's training requirements. Thus progressive changes are starting to occur which will continue to improve future helicopter safety statistics.

7.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

Over the course of this investigation, a number of findings were developed from the analysis of helicopter accident data. The major findings and recommended actions to follow this study are contained in this section.

7.1 SUMMARY OF FINDINGS

1. Helicopter accident rates have improved dramatically over the last 26 years. From a high of 60.57 accidents per 100,000 hours in 1966, accident rates have improved nearly tenfold to 6.22 accidents per 100,000 hours in 1987.

2. Fatal accident rates have improved significantly over the last 26 years. From a high of 4.88 fatal accidents per 100,000 hours in 1966, fatal accident rates have improved nearly fivefold to an average of 1.00 fatal accident per 100,000 hours over the years 1987 through 1989.

3. The percentage of accidents with fatalities has risen over the last 26 years. However, this percentage increase is much lower than the six-fold increase in the number of flight hours during the same period. The lowest percentage of fatal accidents, 6.61 percent, occurred in 1965. The highest value, 19.7 percent, occurred in 1986. If this trend were to continue, by 1995 over 20 percent of the accidents would involve fatalities. This trend reflects the fact that helicopters are getting larger and are carrying more people. This trend also illustrates the need for requiring more crash survival features in helicopters.

4. The number of helicopter accidents per million takeoffs/landings steadily decreased for the period analyzed (1977 through 1986). The decrease during this period for these flight phases was approximately 40 percent.

5. The number of helicopter accidents per million takeoffs/landings is lower than general aviation fixed-wing for the period analyzed (1980 through 1986).

6. Based on NTSB accident data and FAA hours flown data, helicopter accident rates and helicopter fatal accident rates are comparable to general aviation rates over the last 3 years of the study (1987 through 1989).

7. For the study period 1977 through 1986, approximately 34 to 39 percent of all helicopter accidents occurred at or within 1 mile of takeoff/landing sites. Approximately 13 to 18 percent of all helicopter accidents occurred at or near airports, 3 to 5 percent occurred at or near heliports, 9 to 18 percent occurred at or near unimproved landing sites, and 3 to 8 percent occurred at unspecified landing sites. (The range of values represents a 95 percent confidence interval.)

8. Helicopter operations falling within what the FAA and NTSB define as the "personal" mission have by far the highest accident rate, averaging over 100 accidents per 100,000 hours for the years 1983 through 1986. "Business," "instruction," "aerial applications," and "other" work

mission types have accident rates that are higher than the average for all rotorcraft. "Corporate/executive," "aerial observation," and "air taxi" mission types have accident rates that are less than the average for all rotorcraft. The "personal" and "business" mission types have a combined accident rate that is higher in a recent study period (49 accidents per 100,000 hours, 1983 through 1986) than in an earlier study period (32 accidents per 100,000 hours, 1977 through 1979). Of the two mission types, "personal" is the more serious problem (see figure 9).

9. In spite of having a relatively high accident rate when compared to all rotorcraft, the "aerial applications" mission has a relatively low fatal accident rate.

Category	Accidents Per 100,000 Hours	Fatal Accidents Per 100,000 Hours
Aerial Applications	18.3	0.6
All Rotorcraft	10.2	1.6

This may be due, in part, to Part 137.42 of the Federal Air Regulations requiring aerial application aircraft to have shoulder harnesses and to the fact that aerial applications involve one occupant, whereas other missions typically have more occupants.

10. The risk of a fatal or major injury to an occupant of a helicopter (pilot, crew, or passenger) averaged 1.56 fatal/major injuries per 100,000 occupant flight hours during the period from 1977 through 1986. The range of this rate was from a high of 2.42 in 1979 to a low of 0.83 in 1981.

11. The risk of a fatal or major injury to ground personnel around helicopter takeoff/landing sites averaged 0.13 fatal/major accidents per 100,000 flight hours during the period from 1982 through 1986. Over half of these accidents (8 of 15) happened at remote landing sites.

12. The risk of a helicopter accident occurring in a neighborhood in the vicinity of a specific heliport is an extremely rare event. Based on 1983 through 1986 accident rates, the likelihood of an accident near a heliport that has 400 annual helicopter operations is about 1 accident every 495 years. This risk will vary by the number of helicopter operations at the heliport.

13. Measured against the NTSB report, Special Study, Review of Rotorcraft Accidents, 1977-1979, safety programs developed by the helicopter industry and the FAA have been effective in reducing accident rates for several segments of the industry. These segments include "corporate/executive," "aerial applications," "instruction," and "air taxi." These programs have not been effective in reducing "personal" and "business" accident rates. Previous FAA and industry studies (reference 3, 10, and 18) report approximately the same level of reduced accidents and reflect the impact of safety programs on reducing the overall accident rate.

14. The number of landing site design-related mishaps (1982-1986) in which the landing site design is a direct factor in the mishap is estimated to be less than 5 percent per year for all landing sites and 3 percent or less per year at heliports.

15. The number of landing site design-related mishaps that occur at landing sites designed in accordance with the Heliport Design Advisory Circular (reference 15) is estimated to be less than 2 percent per year and less than 1 percent per year at heliports.

16. The findings of this report are based on the combined mix of the helicopter fleet (single-engine piston, single-engine turbine, twin-engine turbine). As the fleet size (aircraft numbers and operational hours) changes, the accident rates can change significantly. This is especially true of accident rates within those types of operations (missions) where some types of helicopters are used in higher risk missions and in those missions where limited funding is the driving force. With these thoughts in mind, it is appropriate to apply these conclusions carefully.

7.2 RECOMMENDATIONS

Based on the study findings, the following recommendations are offered:

1. The FAA and the helicopter industry should continue to develop and implement an approach aimed at reducing accidents and injuries. In addition, further efforts should be directed at the "personal" and "business" mission types.

2. The helicopter ground-taxi/hover-taxi accident rate has been growing rapidly since 1981. The FAA and the helicopter industry should develop and implement an approach aimed at reducing the growing number of helicopter ground operation accidents.

3. The FAA and the helicopter industry should adopt specific projected accident rates and target levels of safety to be achieved at 5 year intervals. Furthermore, these projected accident rates and target levels of safety should be used as management tools to develop effective safety programs.

   Four helicopter safety parameters should be monitored on an annual basis and compared with projected accident rate values computed from recent historical data. These four parameters and their projected values for the year 2000 are:

Safety Parameter	Projected Value in the Year 2000
Helicopter Accident Rate	3.6 per 100,000 hours
Helicopter Fatal Accident Rate	0.7 per 100,000 hours
Takeoff/Landing Accident Rate	3.8 per million takeoffs/landings
Ground-Taxi/Hover-Taxi Accident Rate	3.0 per million ground operations

Four target levels of safety are recommended in this study as goals to be achieved by the year 2000. These target levels of safety should be considered in the development of landing site design standards and design practices. The landing site accident rates apply to design-related accidents at helicopter landing sites in general and include accidents at airports, heliports, and other prepared sites. The heliport accident rates include only accidents at landing sites specifically categorized as heliports. These target levels of safety are:

Design-Related Safety Parameter	Target Level of Safety in the Year 2000
Landing Site Accident Rates	1.2 per 10 million takeoffs and landings
	1.0 per 10 million ground operations
Heliport Accident Rates	0.8 per 10 million takeoffs and landings
	0.6 per 10 million ground operations

These goals, derived from improvements observed over the last 10 years, are ambitious but could be achieved with aggressive awareness, training, and risk management programs.

4. The FAA should repeat this study at approximately 5 year intervals. The purpose of repeating the study is to determine if projected accident rates and target levels of safety are being achieved and to identify areas of the helicopter industry where safety improvements are needed.

5. To determine a more accurate estimate of the number of landing site design-related mishaps as well as the number of heliport design-related mishaps, the FAA should conduct an in-depth study of landing site mishaps over a 6 to 12 month period. This effort should employ accident investigation methods and would need to determine which landing sites were designed in accordance with the Heliport Design Advisory Circular. This effort would develop the actual risk exposure for landing sites designed in accordance with current standards versus those which do not meet the Heliport Design Advisory Circular criteria.

6. The entire aviation industry should support the National Transportation Safety Board and its accident investigation efforts. Complete, comprehensive, and accurate accident reports are essential to understanding why accidents happen. These reports, both individually and collectively, are also extremely useful for identifying methods of improving aviation safety.

7. The entire aviation industry should support the FAA's efforts to determine operating hours in the annual survey. When operating hours are underreported, it makes the accident rate appear worse than it actually is. This has been a particular concern with rotorcraft operating hours.

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LIST OF ACRONYMS

AAC	Advanced Aviation Concepts
ADM	Aeronautical Decisionmaking
AOPA	Aircraft Owners & Pilots Association
CAA	Civil Aviation Authority
CEPET	Cockpit Emergency Procedure Expert Trainer
CFRS	Crash Resistant Fuel System
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAR	Federal Aviation Regulation
HSAC	Helicopter Safety Advisory Council
IFR	Instrument Flight Rules
NPRM	Notice of Proposed Rulemaking
NTSB	National Transportation Safety Board
PDM	Pilot Decisionmaking
RSI	Risk of Serious Injury
SCT	Systems Control Technology
TLOS	Target Level of Safety

APPENDIX A
DEFINITIONS OF MISSION CLASSES

1. CORPORATE/EXECUTIVE - company flying with a professional crew.

2. BUSINESS - Individual use of an aircraft for business transportation.

3. PERSONAL - Flying for personal reasons (excludes business transportation).

4. INSTRUCTIONAL - Flying under the supervision of a flight instructor (excludes proficiency flying).

5. AERIAL APPLICATION - Agriculture, health, forestry, cloud seeding, firefighting, insect control, etc.

6. AERIAL OBSERVATION - Aerial mapping/photography, survey, patrol, fist spotting, search and rescue, hunting, highway traffic advisory, sightseeing (not FAR Part 135), etc.

7. OTHER WORK USE - Construction work (not FAR Part 135), helicopter hoist, parachuting, aerial advertising, towing gliders, etc.

8. SCHEDULED COMMUTER - Performs, under FAR Part 135, at least five scheduled round trips per week or carries mail.

9. AIR TAXI - FAR Part 135 passenger and cargo operations excluding commuter air carrier.

10. OTHER - Experimentation, R&D, testing, demonstrations, government, air shows, air racing, etc.

11. AIR CARRIER - Performs under FAR Part 121, Part 125, Part 127.

APPENDIX B
OVERALL ACCIDENT RATE COMPARISON - HELICOPTERS TO FIXED-WING AIRCRAFT

Type Use	Year	Helicopter	General* Aviation	Air* Carrier	Scheduled* Commuter
Accidents/100,000 hours flown	1980	12.92	8.76	0.27	3.23
	1981	10.84	8.68	0.38	2.42
	1982	12.30	8.83	0.28	2.08
	1983	11.14	8.67	0.35	1.07
	1984	10.62	8.37	0.21	1.21
	1985	10.40	8.18	0.26	1.16
	1986	8.11	7.56	0.23	0.93
Accidents/100,000 mission segments	1980	6.45	6.45	0.35	2.14
	1981	5.50	6.48	0.49	1.63
	1982	6.18	6.59	0.37	1.33
	1983	5.65	6.47	0.46	0.69
	1984	5.39	6.25	0.29	0.78
	1985	5.28	6.10	0.37	0.78
	1986	4.12	5.64	0.32	0.56
Fatal Accidents/ 100,000 Hours Flown	1980	1.97	1.57	0.01	0.68
	1981	1.23	1.71	0.06	0.64
	1982	2.08	1.66	0.06	0.38
	1983	1.45	1.60	0.06	0.13
	1984	1.56	1.54	0.01	0.40
	1985	1.72	1.53	0.08	0.35
	1986	1.60	1.41	0.02	0.12
Fatal Accidents/ 100,000 Mission Segments	1980	1.00	1.17	0.02	0.45
	1981	0.62	1.28	0.08	0.44
	1982	1.06	1.24	0.08	0.25
	1983	0.74	1.19	0.08	0.09
	1984	0.79	1.15	0.02	0.26
	1985	0.87	1.14	0.12	0.23
	1986	0.81	1.05	0.03	0.08

* Fixed-Wing

APPENDIX C
DEPARTURE, APPROACH, AND GROUND OPERATIONS ACCIDENTS
(1977 THROUGH 1986)

TAKEOFFS

YEAR	HELICOPTERS	GENERAL AVIATION*	AIR CARRIER*	SCHEDULED COMMUTER*
1977	48			
1978	51			
1979	51			
1980	47	694	1	10
1981	48	727	2	4
1982	44	653	4	8
1983	53	627	4	4
1984	40	617	2	2
1985	29	511	9	3
1986	36	518	2	2

LANDINGS

YEAR	HELICOPTERS	GENERAL AVIATION*	AIR CARRIER*	SCHEDULED COMMUTER*
1977	50			
1978	52			
1979	47			
1980	60	1377	7	11
1981	75	1257	4	13
1982	54	1106	5	4
1983	39	1030	[illegible]	4
1984	43	996	3	8
1985	30	956	4	11
1986	17	845	6	7

GROUND OPERATIONS

YEAR	HELICOPTERS	GENERAL AVIATION*	AIR CARRIER*	SCHEDULED COMMUTER*
1977	34			
1978	41			
1979	31			
1980	36	136	4	10
1981	34	103	11	5
1982	37	137	4	5
1983	35	126	2	5
1984	42	120	3	4
1985	44	92	1	1
1986	39	91	4	2

* Fixed-wing

Note: "Scheduled Commuter" accident data was included with the "General Aviation" data prior to 1980. Therefore, the number of fixed-wing "General Aviation" and "Scheduled Commuter" accidents which occurred during the various flight phases were not determined prior to 1980.

APPENDIX D
ESTIMATES OF ANNUAL DEPARTURES, APPROACHES, AND GROUND OPERATIONS
(1977 THROUGH 1986)
(in millions)

TAKEOFFS(1)

YEAR	HELICOPTER	GENERAL AVIATION*	AIR CARRIER*	SCHEDULED COMMUTER*
1977	3.75			
1978	4.48			
1979	5.13			
1980	4.70	5.18	5.48	1.78
1981	5.40	5.09	5.33	1.83
1982	4.72	4.57	5.09	2.03
1983	5.56	4.42	5.17	2.33
1984	5.01	4.50	5.60	2.68
1985	4.33	4.28	6.01	2.56
1986	5.27	4.26	7.24	2.66

LANDINGS(2)

YEAR	HELICOPTER	GENERAL AVIATION*	AIR CARRIER*	SCHEDULED COMMUTER*
1977	3.75			
1978	4.48			
1979	5.13			
1980	4.70	5.18	5.48	1.78
1981	5.40	5.09	5.33	1.83
1982	4.72	4.57	5.09	2.03
1983	5.56	4.42	5.17	2.33
1984	5.01	4.50	5.60	2.68
1985	4.33	4.28	6.01	2.56
1986	5.27	4.26	7.24	2.66

GROUND OPERATIONS

YEAR	HELICOPTERS(3)	GENERAL AVIATION*(4)	AIR CARRIER*(4)	SCHEDULED COMMUTER*(4)
1977	7.51			
1978	8.95			
1979	10.27			
1980	9.40	10.36	10.96	3.56
1981	10.79	10.18	10.66	3.66
1982	9.44	9.14	10.18	4.06
1983	9.13	8.84	10.34	4.66
1984	10.03	9.00	11.20	5.36
1985	8.66	8.56	12.02	5.12
1986	10.55	8.52	14.48	5.32

(1) Includes takeoff and departures within 1 mile
(2) Includes approaches within 1 mile and landings
(3) Includes standing, taxi, and hover
(4) Includes standing and taxi
* Fixed-wing

Note: The number of fixed-wing accidents in the various categories prior to 1980 were not determined. Therefore, the number of fixed-wing departure, approach, and ground operations are not included here.